IRIA Proceedings of an IR Seminar

EXPANSION OF INFRARED TECHNOLOGY INTO THE CIVILIAN MARKET

September 1972

A. J. LaRocca
Chairman

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This report consists of an Introduction by the Seminar Chairman, nine technical papers on civilian applications of infrared imaging, the synopsis of a panel discussion, and several letters from seminar participants.

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PREFACE

These are the proceedings of a 20 September 1972 seminar on the "Expansion of Infrared Technology into the Civilian Market" which was conducted at The University of Michigan by the Infrared Information and Analysis (IRIA) Center. This Center, supported by ONR Contract N00014-73-A-0321-0002, is in the Infrared and Optics Division, which on 1 January 1973 became part of the Environmental Research Institute of Michigan (ERIM). IRIA is sponsored under the ONR Physics Program and sanctioned by the Department of Defense to collect, analyze and disseminate information on infrared technology with special emphasis on the military applications. These proceedings are a first formal attempt to direct a small part of IRIA's attention to the civilian market.

IRIA provides references to scientific and technical documents on request; and may provide substantive answers to specific technical questions and information concerning current research and development projects. It publishes periodic annotated bibliographies, the Infrared Newsletter, the Proceedings of the Annual Infrared Information Symposium (Proc.IRIS), and proceedings or minutes of the Specialty Groups of IRIS. IRIA also sponsors other symposiums, and publishes other reports, such as state-of-the-art reports on various topics in infrared.

The Infrared and Optics Division of ERIM is available for consultation to all industries on matters concerning infrared and optics. IRIA-IRIS membership is obtainable on an annual subscription basis and includes all the meetings, the publications, and the bibliographic and other services of the IRIA Center. Membership is open to all organizations with cleared facilities and the appropriate need-to-know. Further information on access to general or specific subject-matter can be obtained by writing:

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Ann Arbor, Michigan 48107

EXPANSION OF INFRARED TECHNOLOGY
INTO THE CIVILIAN MARKET

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INTRODUCTION

A. J. LaRocca
Environmental Research Institute of Michigan
Ann Arbor, Michigan

The conference was held under the auspices of the Environmental Research Institute of Michigan's IRIA (Infrared Information and Analysis) Center. The purpose was to make an initial attempt to hear the views of some of the experts in the field of Infrared Technology and its associated fields regarding the topic of Infrared in the civilian market.

The most significant remarks that can be made to introduce the topic of this meeting have already been published and, hopefully, read by a large number of the Infrared community through the medium of the Infrared Newsletter, published by IRIA. The message in that publication came in the form of an IR Issue Paper which is reproduced here.

> "Infrared (IR) Technology, with years of support by military R&D, has produced many operational systems and components for the Armed Services in what is currently a multimillion dollar industrial program. Yet we see relatively little application in the civilian market. Why is this? Why is there not a comparable generation of products for the civilian/industrial markets?
>
> "Perhaps IR actually has very little application, but one's intuition is that this conclusion is unwarranted and has little supportive evidence. Perhaps the level of civilian market action reflects the absence of a link between infrared technological output and certain problems affecting the civilian and industrial domain. The manifestation of this link would be centered in research and analysis designed to help promote and stimulate productivity in this sphere of activity by offering a "library" of IR technology now in reports, documents, and journals, by citing current successful ventures, by demonstrating techniques for converting from established military-oriented to civilian-oriented technology, by signifying attractive avenues for new venture, and by educating user industries in the uses and techniques of IR. No such link exists today for the field of civilian-oriented IR technology.
>
> "Quantification of the statement that there is relatively little application in the civilian market is difficult and non-existent today. If there were a definitive method of measuring the success of the use of IR in military applications, we might have either an

answer to the question or a gauge to the possible success of its thrust into the civilian market. Unfortunately such a method does not exist. Even if it did, its application to an analysis of successful civilian activity would pose problems because of the different constraints on the marketability of a product in military and civilian use. Civilian-industrial applications will certainly be different from those in the military. In addition, requirements on products for civilian applications are often not as stringent, so that compromises can be made regarding the limitations under which components can be used or operated.

"Citing the large support of IR programs in Defense contracts, it might be suggested that the paucity of civilian backing of IR technology is a result of the past near-subsidization by the military, with infrared constituting a minor segment of some large industries and a major portion of a few small companies. Under these circumstances it would naturally be difficult, if not undesirable, to project marketing awareness outside of those avenues through which attractive money flows. In addition, security classification has often imposed restrictions which precluded the practicality of courting the open market.

"As a result of the activities of IRIA (Infrared Information and Analysis) Center at the Willow Run Laboratories of the Environmental Research Institute of Michigan, which has for many years successfully operated as an information link between the military services and IR specialists, we are aware of some civilian applications of IR technology. For example, IR technology is already engaged peripherally in medicine by clinical use of devices in the detection of tumors and vascular and other disorders. In the remote sensing of the environment, IR has already proved a useful tool in efficient data acquisition in such areas as agriculture, forestry, environmental quality, and mineral resources. In addition, because of the spectral characteristics of many air pollutants, IR has been shown to be a potentially useful tool for detection and monitoring. This area apparently has yet to be explored with a vigor commensurate with its potential.

"A conference which would allow infrared technologists to discuss potentially attractive IR applications that are civilian-market directed, is a logical first step in addressing these issues. IRIA/IRIS affords an avenue to reach today's infrared community. We plan such a conference on their behalf and will make every effort to reach the much larger community of potential users."

The topical matter of the meeting was designed to address some of the issues and the presentations were intended either to answer certain questions about blockages to the transfer of IR technology from military to civilian, or demonstrate examples of blockages we were not previously aware of. Zissis' informal comments indicate that there is at least one formal outlet for exchange of information between producer and user of IR. He described IRIA and cited its involvement in civilian-oriented Infrared.

We included two distinctly user-oriented papers at the outset to portray circumstances under which IR is successfully applied in the civilian (industrial) sector. The paper by Lowe on Airborne Scanners was included to show that the more-or-less large scale military uses of IR technology are nearly directly transferable to spheres of interest outside of the military. But Limperis' talk on Non-Imaging Sensors was designed to show that the civilian market embraces the user whose needs are widespread and variable, and is satisfied usually only when the cost benefit is immediately visible, and preferably if the device is cheap.

Steiner's topic was considered timely, not only from the point of view of the Bureau of Standard's interaction with the IR product line, but also in regard to the Bureau's own program of evaluating arrangements with industry on incentives which will increase its desire to innovate.

The last three topics of the program were included to help us get first hand information from component manufacturers about the prognosis for meeting the all-important requisite of low cost in future IR systems, based on some of the factors that determine the cost. This phase of the program could have been expanded considerably, but for the sake of time, we limited the subject matter, for the present, to the state of detectors, filters and cryogenics.

Because only a few people were able to attend, it was intended that the information be made available to as large as audience as possible, in as short a time as possible, by quickly publishing the proceedings. A lag in the submission of printed material in some cases defeated our attempt to publish quickly. In order that there be no further delay we decided to shoot and print the material that was sent, and transcribe from tape what was not made available otherwise. Therefore, there has been no editing of written material, or processing of photographs and other figures. The opinions and views stated in the papers are those of the authors alone and do not necessarily reflect those of IRIA, the Environmental Research Institute of Michigan, or the sponsors of IRIA.

To the extent that interest in the topic of civilian IR is amplified as a result of this meeting, we hope to hold others, and pry more deeply into matters concerning a more dedicated involvement by IR people in effecting the realization of an expanded IR civilian market.

WHY IRIA IS INTERESTED IN CIVILIAN IR*

G. J. Zissis
Director of IRIA
Environmental Research Institute of Michigan
Ann Arbor, Michigan

The idea that a meeting like this might be useful came about in this fashion. One day Tony LaRocca came into my office, and said, "Why is it that infrared gadgets aren't being sold and making millions and millions of dollars?" And my answer to him was, "Tony, for all we know they are." He replied, "You may be right." So we started trying to determine what were the right questions to ask about the civilian market and uses of infrared.

It is at least reasonable to say that for many purposes in military systems, infrared technology has become useful enough that it is considered cost-effective. If infrared technology is useful in that sense, then what about its uses in the civilian market?

Before I explain IRIA's involvement, it may be that I should explain IRIA, since the concept of IRIA may be a new one for some of you. IRIA is the Infrared Information and Analysis Center, set up in the mid-fifty's under an ONR contract with triservice support. The ONR Physics Division has been the technical monitor since IRIA's inception. This was one of the actions recommended to the Department of Defense by an in-depth study done by the so-called Metcalf Committee. Their study recommended several actions to be taken if infrared were to become useful for defense purposes. One of these was the creation of an agency or an institution or a center to expedite information exchange. This information flow, especially in the classified domain, is very difficult to encourage and maintain. That is the reason for setting up IRIA, a center that was to collect, analyze, and disseminate information on infrared, and, more recently, on electrooptics.

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*Informal comments transcribed from tape recordings made during the meeting.

One product from IRIA was the "Handbook of Military Infrared Technology". I assume everyone here is familiar with this inexpensive, useful book, edited by Bill Wolfe, who was then Director of IRIA. That's what I mean by infrared technology. This is not to arbitarily exclude lasers from our consideration but as soon as you talk about electrooptics and laser technology, you talk about a wider, diffuse civilian market. An awful lot that you are going to hear today will not be that complete or that broad. While we may wish to discuss some of the components that are involved in electrooptics, such as light-emitting diodes, I think we ought first to be sure to cover the elements of infrared technology represented by the Handbook. Topics can be like thermography, detectors of different types, components, optical materials, framing and non-framing scanners, control devices, etc. In general, these cover the region from one to fifteen micrometers.

We have prepared and distributed what we have called an issue paper*. As you have seen the questions it contains are, "Why hasn't infrared grown bigger and better in the civilian market? Has it done as well as it should have done? Is that the size of the market today? What is the forecast for the market in the future, say, five to ten years from now? Is there something wrong with the way we are going at it? Should the federal government change what it does in supporting R & D, or in its structure in relation to industry? Should it change our posture for selling U.S. technology overseas and within the United States so as to stimulate our marketing development?"

Thus our questions are aimed at seeing if there really is a problem and just what it is. I can imagine someone saying, "There is no problem because the market is as active as it can ever be and you have over-estimated what anyone might find there." I can also imagine somebody else saying, "We think that market is certain to grow bigger, at least in selected areas, and no matter what anybody else thinks we intend to go out and get it, and we think we know how." It could be that still someone else would say that they are not handicapped by federal government regulations like those covering export of arms and munitions. Instead they may feel no significant motivation since they are more than happy with the market in military infrared technology.

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*Reproduced in its entirety in the Introduction by A. J. LaRocca

I hope that we can better formulate these questions - that is a major purpose of this meeting. We wanted to get together those people that want to talk about the questions that exist in this area. It is no secret that the present administration has identified the problems of technology utilization and the stimulation of R & D within American industry as one of its goals. William McGruder has spoken many times about programs to stimulate the private sector to begin to do research and development. If this conference is fruitful, if what we do here begins to make sense, I would hope we could consider a continuing working group, or series of meetings, or a similar kind of activity.

Application of Infrared Imaging to Determine Insulation Characteristics of Dwellings

M. B. Lacher
Owens-Corning Fiberglas Corporation
Granville, Ohio

Good morning. I'm Mike Lacher of the Owens-Corning Fiberglas Corporation Product Testing Laboratories. Owens-Corning Fiberglas is primarily a thermal insulation manufacturer, and because the normal function of thermal insulation is to control heat flow we have found ourselves deeply involved with current concerns about the ecology and energy shortages. We feel that we have responsibilities in the areas of: Determining how best to utilize existing insulation systems, developing more effective insulations and insulation systems, and devising construction techniques to improve the efficiency of energy utilization in buildings.

Published data presently used in calculating heat gain or loss in buildings is based largely on the results of small scale testing and on calculated thermal performance values. It thus doesn't take into account "real world" conditions where "loose" construction, air leakage, and convection effects can be present.

In order to get an idea of what the present situation is, we mounted our real-time infrared camera in a van and took a ride. We videotaped what we saw - both visually and infrared (slides 1 and 2)

Here we see a typical ranch style house. As you can see from the snow, this was done in cold weather, and so we would expect detectable heat losses to be occurring. (slide 3)

The most obvious heat loss areas of this fairly well insulated house are the windows. By the way, the window at the right of the picture appears cold because it is in an unheated garage, with the door open. (slides 4 and 5) Notice the heat going out the furnace flue in upper left.

This exercise provided some interesting qualitative data and proved to us that our unit could differentiate between areas of high and low heat loss as encountered in typical residential construction. Because of the difficulty of controlling indoor temperatures precisely and in obtaining uniform construction it became apparent that while the infrared camera could be useful in determining whether or not construction errors existed in completed structures, it was not a useful design aid when used as just shown.

Owens-Corning then constructed the Large-Scale Thermal Performance Tester. This apparatus precisely measures heat flow through 9' X 14' wall sections by maintaining a temperature differential across a wall section and metering electrical power required to maintain the selected temperature differential.

(Slide 6) The tester consists of two polyurethane foam boxes with 18" thick walls and a Fiberglas reinforced plastic surface treatment. The thermal resistance value of these boxes is 100 as compared to insulated building walls which have thermal resistance values in the range of 10 to 15. (slide 7)

In this view the warm side has been opened and the warm or interior side of a test wall can be seen. In this particular wall we have included top and bottom construction details, that is joist ends etc. The joist ends at the top have been boxed in and vented out of the tester so that air infiltrating the wall can migrate into the equivalent of an attic space. The warm side box has air diffusers near the top and bottom. A fan, baffles, and heaters are behind the panels on the warm box. (slide 8)
Here we can see the cold or exterior side of the test wall. It consists of 10" redwood lap siding over wood fiber sheathing.

Air pressure differentials can be imposed on test constructions and the effects of wind induced air infiltration can be measured. Our pressure tests have been conducted with a pressure differential of 0.25 inches of water, which corresponds to a wind velocity of approximately 30 miles per hour. The temperatures selected for normal testing are 75°F and -20°F. This represents a typical severe winter condition. The equipment is housed in a room whose temperature is controlled at 75°F. This permits removal of the metering (warm) side enclosure without significantly changing heat flow through the test wall. At this point it can be examined with the infrared camera. Any unpredicted heat flow patterns can then be detected and investigated. (Slide 9) Here is a thermogram of an uninsulated wall constructed of 2 X 4's on 16 inch centers. Of significance here are the facts that the studs are warmer and are thus better insulators than the air spaces between them and that a vertical temperature gradient exists in the wall. This indicates that convection currents exist in the cavities. Assuming that these cavities are dead air spaces would be incorrect.

This, the thermogram tells us instantly. The rectangular object toward the lower right is a device we use as a temperature comparator. It consists of two painted aluminum plates that are cooled thermoelectrically and maintained at temperatures approximately 2°F apart. The emissivity of the comparator plates is close to that of the wall surface. In this particular shot, the comparator temperature difference was 2.3°F. (slide 10) In this slide we can see the temperature comparator in place in front of the test wall of the previous slide. The surface of the test wall is conventional 1/2" thick gypsum wallboard. The joints between the wallboard sections have been taped but not spackled. The wiring on the wall is a network of thermocouples for recording surface temperatures. (slide 11) This is a view of the exterior or cold side of this test wall. It's surface consists of 10" redwood lap siding over conventional 1/2" wood fiber sheathing. The thermocouples on this side of the wall are directly opposite those on the warm side. In case you're wondering how we read all these thermocouples, I'll briefly explain. The surface thermocouples, plus an equal number of air thermocouples, plus their reference junctions, plus pressure tranducer outputs are fed through a scanner to a teletypewriter that records up to 100 data channels on printout and punched tape. The punched tape is read into a computer which tabulates data and calculates thermal transmittance values. (slide 12) In this thermogram of an uninsulated wall we have superimposed a single line scan. The location of the single scan is denoted by the horizontal cursor line across the picture. There is noticeable electronic "hash" in the single line trace when looking at small temperature differences, but the warm area at each 2 X 4 wall stud is clearly shown by a peak at each stud. If we choose our cursor line location such that it includes our temperature difference comparator we can have a graphic indication of the relationship of vertical displacement in the single line scan to temperature difference. I'll show that a little later. (slide 13)

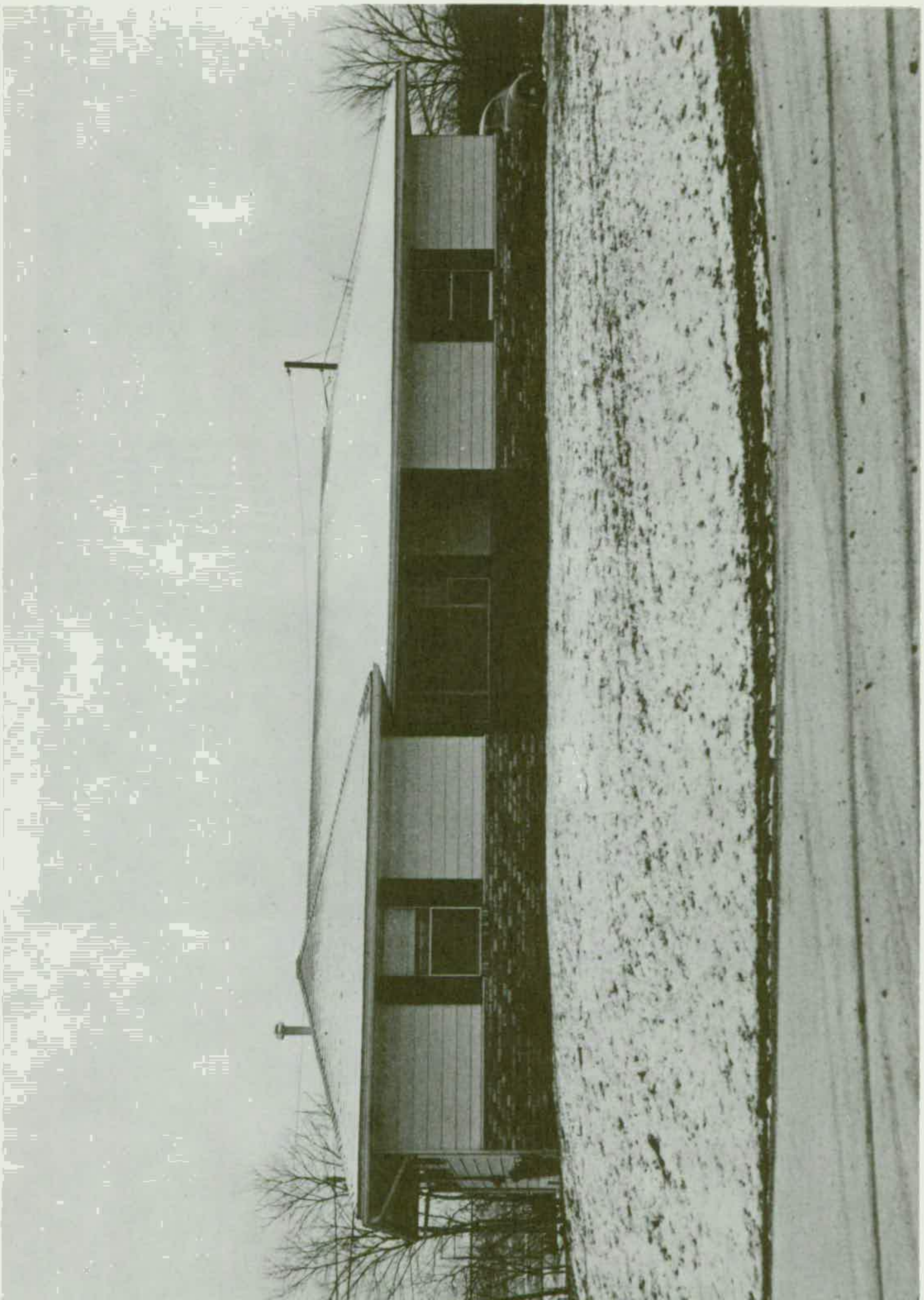
Next, let's look at an insulated wall. This is another 2 X 4 stud wall, but with Fiberglas 3-1/2 inch paper faced insulation. The exterior and interior surface treatments will be the same as the uninsulated wall we've already seen. (slide 14) Now the 2 X 4's appear dark rather than light. They are a better insulator than an air space, as we saw before, but they are not as good as insulation batts. Notice that the single line scan shows a distinct dip over each stud. (slide 15) Here is the same shot,

but with the location of the single line trace dropped down to cross the temperature differential comparator The two sharp peaks are from the sides of the comparator case so we'll ignore them. The two painted plates of the comparator are clearly indicated, however, and they correspond to a measured temperature difference of 2.1°F in this view. We can measure other distances on the single line trace and infer the corresponding temperature differences.
(slide 16) This view shows the upper portion of the same test wall with a pressure differential of 0.25 inches of water across it. In this case the infrared camera revealed to us that we had air leakage at the top of the wall. The cold air leaking around the top edge of the wall and cascading down the wall surface is quite apparent. (slide 17) Here is the same view electronically processed to give a 3D effect. This is done by introducing a delay in each succeeding horizontal scan and by superimposing some of the Z , or intensity signal on the Y signal. This technique can be used to help the viewer orient himself when observing more difficult subject matter, enabling him to better understand what he is seeing. (slide 18)

In addition to plain wall sections, we have examined walls containing windows and doors. This slide shows a test wall with a standard 3' X 6' -8" solid wood door. This is the exterior side showing the same type wood siding as before. The wall area outside the door is the same as before -- 2 X 4 studs on 16" centers with 3-1/2" thick Fiberglas insulation between the studs.

(slide 19) We also tested this same configuration with an aluminum storm door. (slide 20) This is a view of the warm side of this same test wall. (slide 21) This is what our wood door wall looked like in infrared. A number of windows that we have tested show similar performance. The moral of the story is: the fewer windows and doors, the lower the fuel bills. Whether the infrared camera will lead to new and improved insulation systems, construction methods, and building component designs still remains to be seen.

Slide 1



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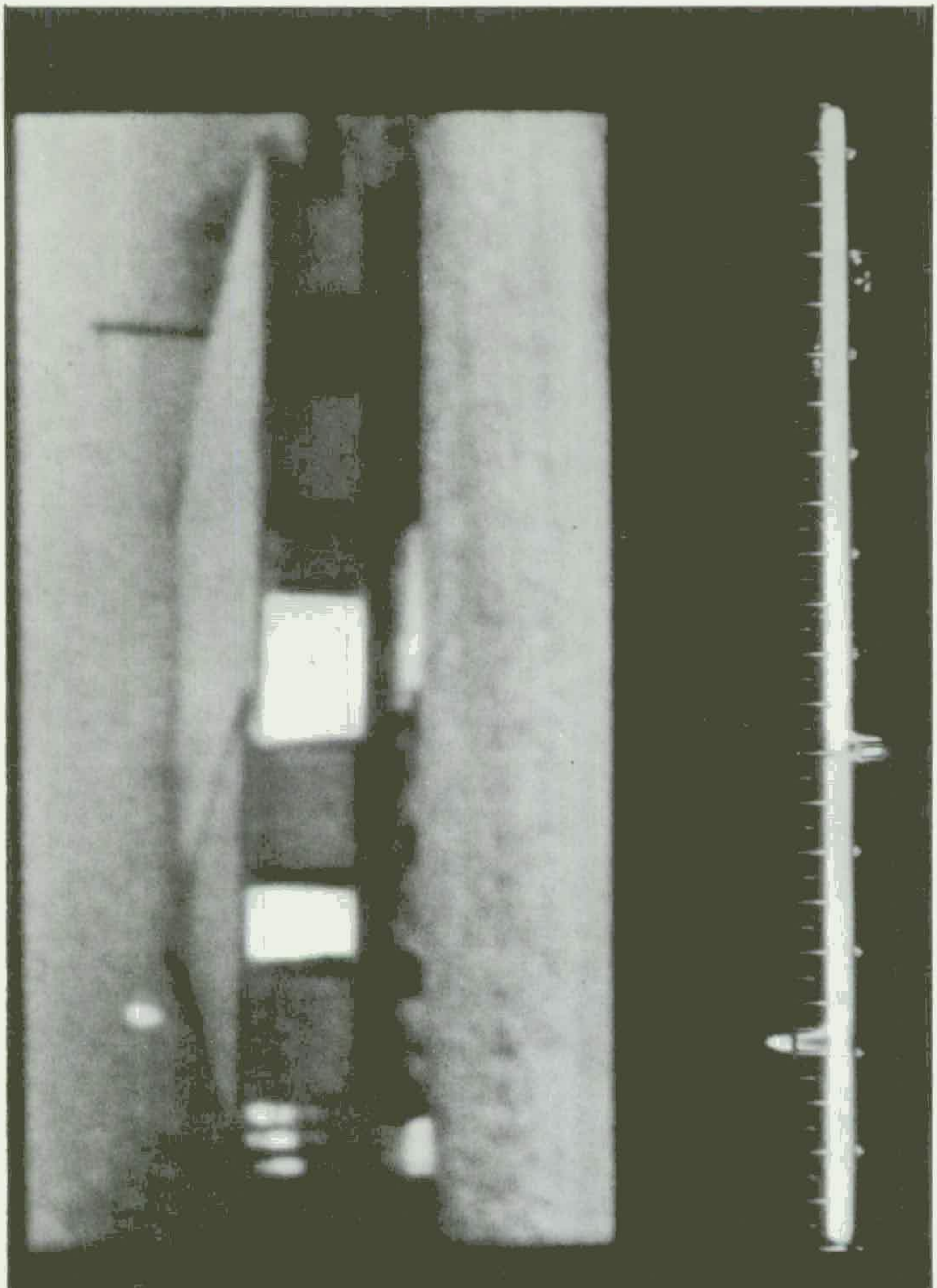

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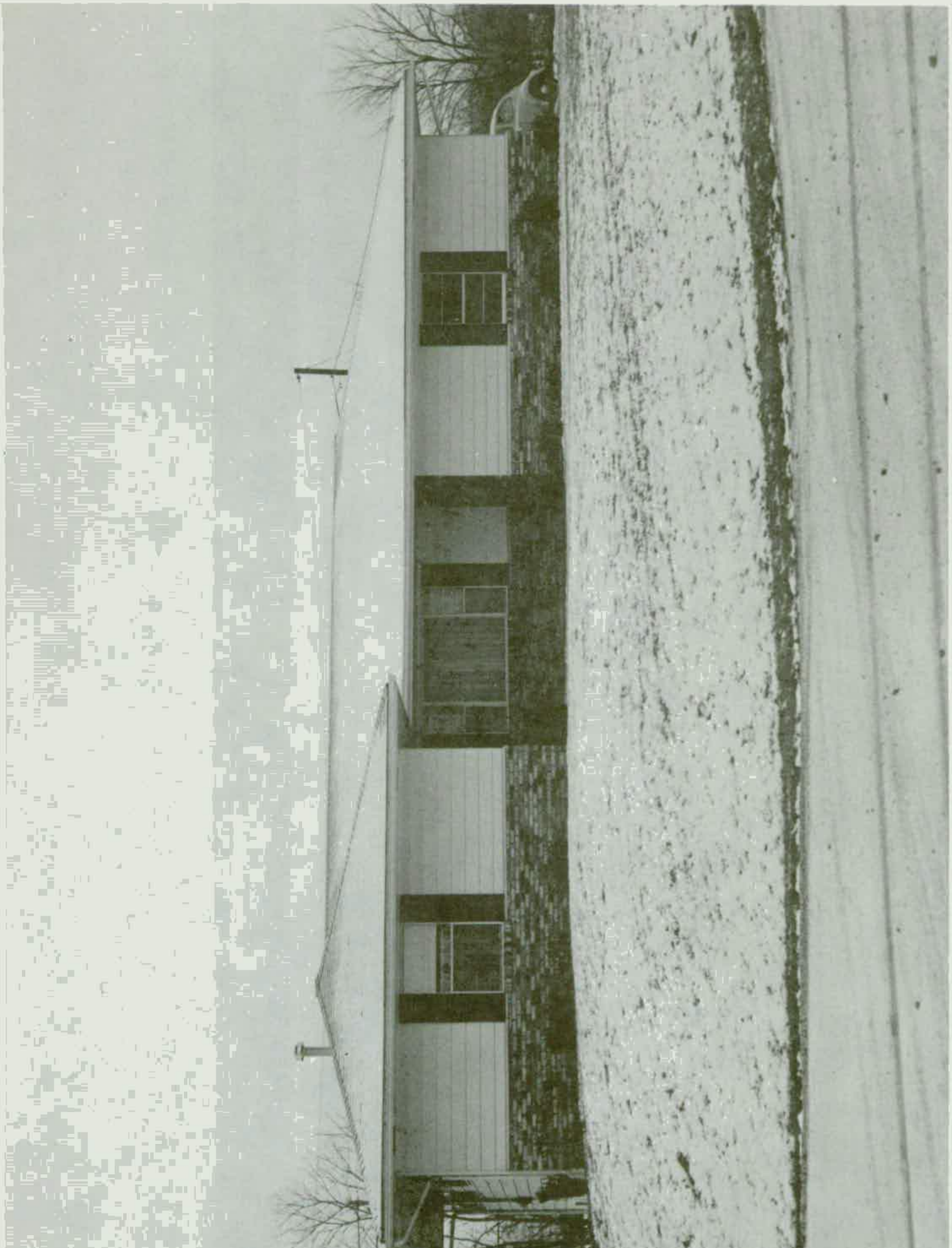

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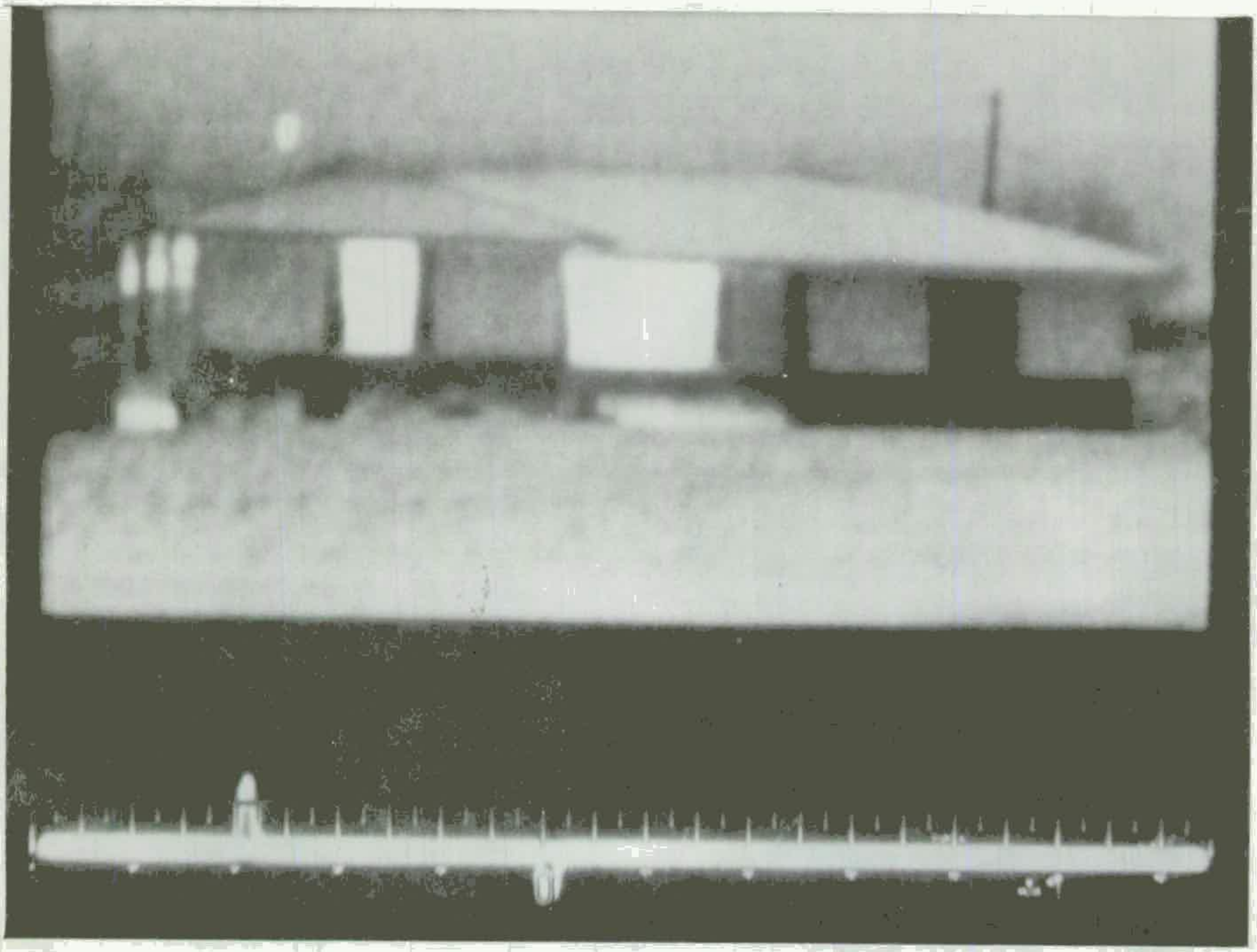

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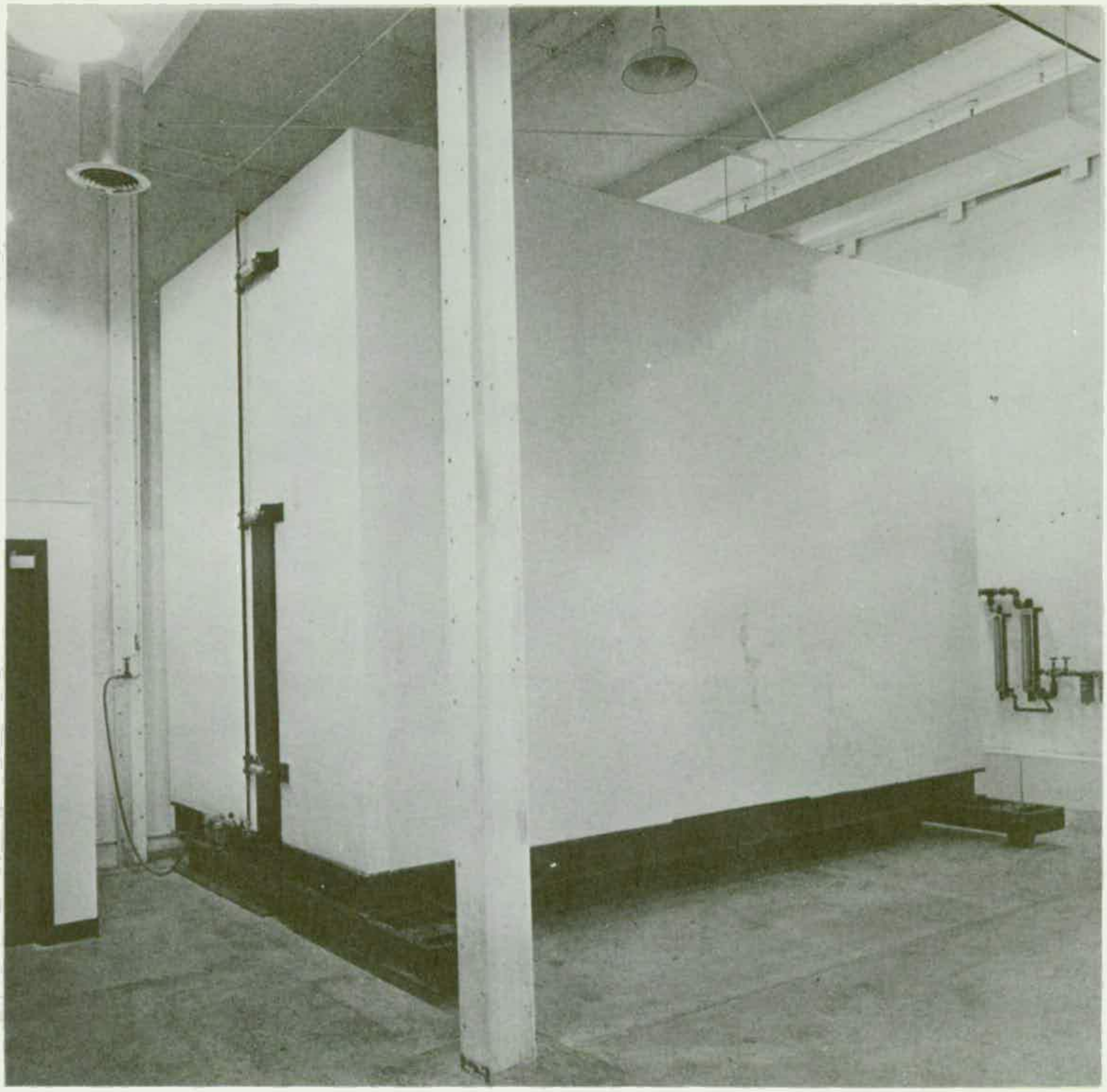

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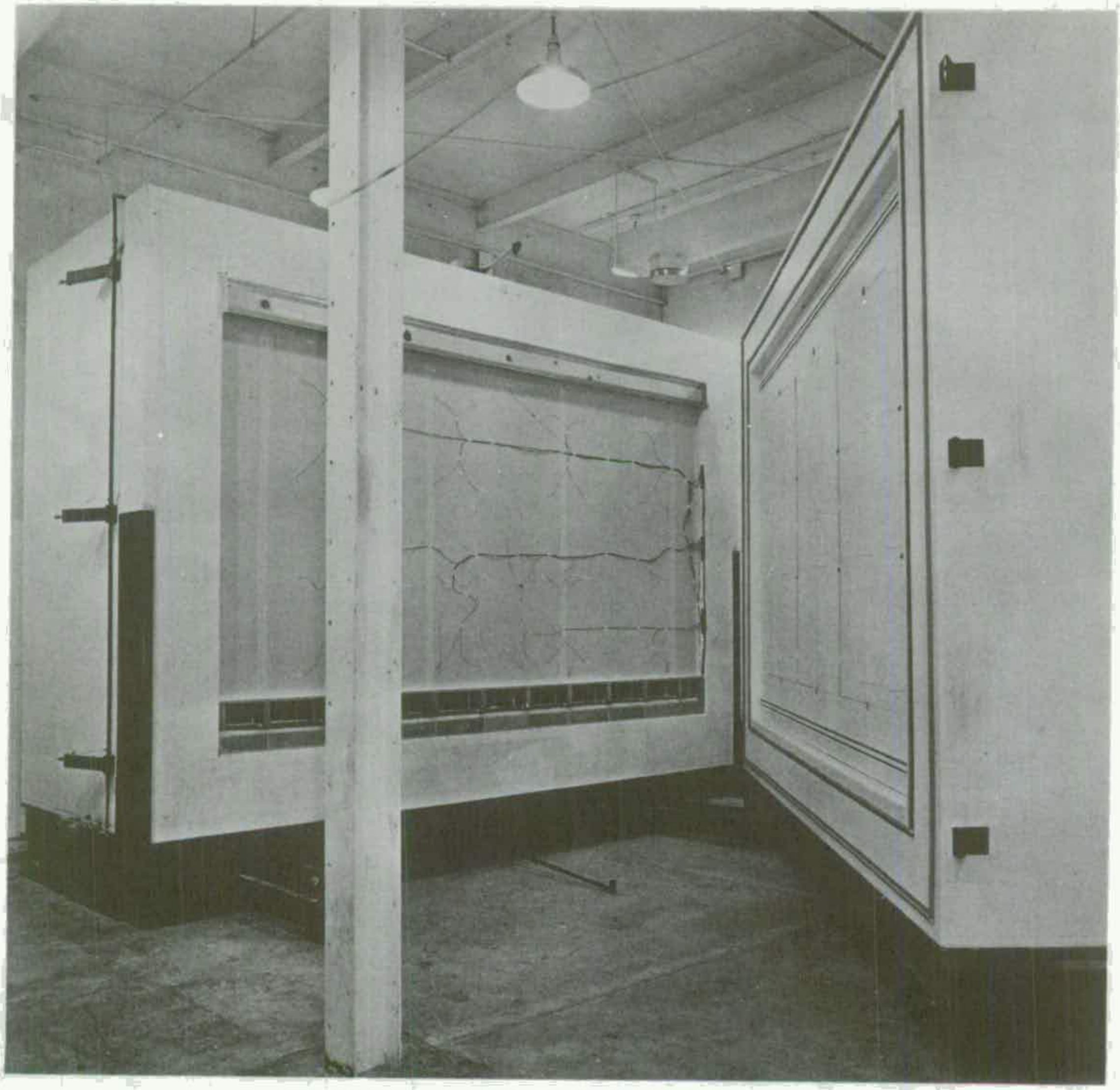

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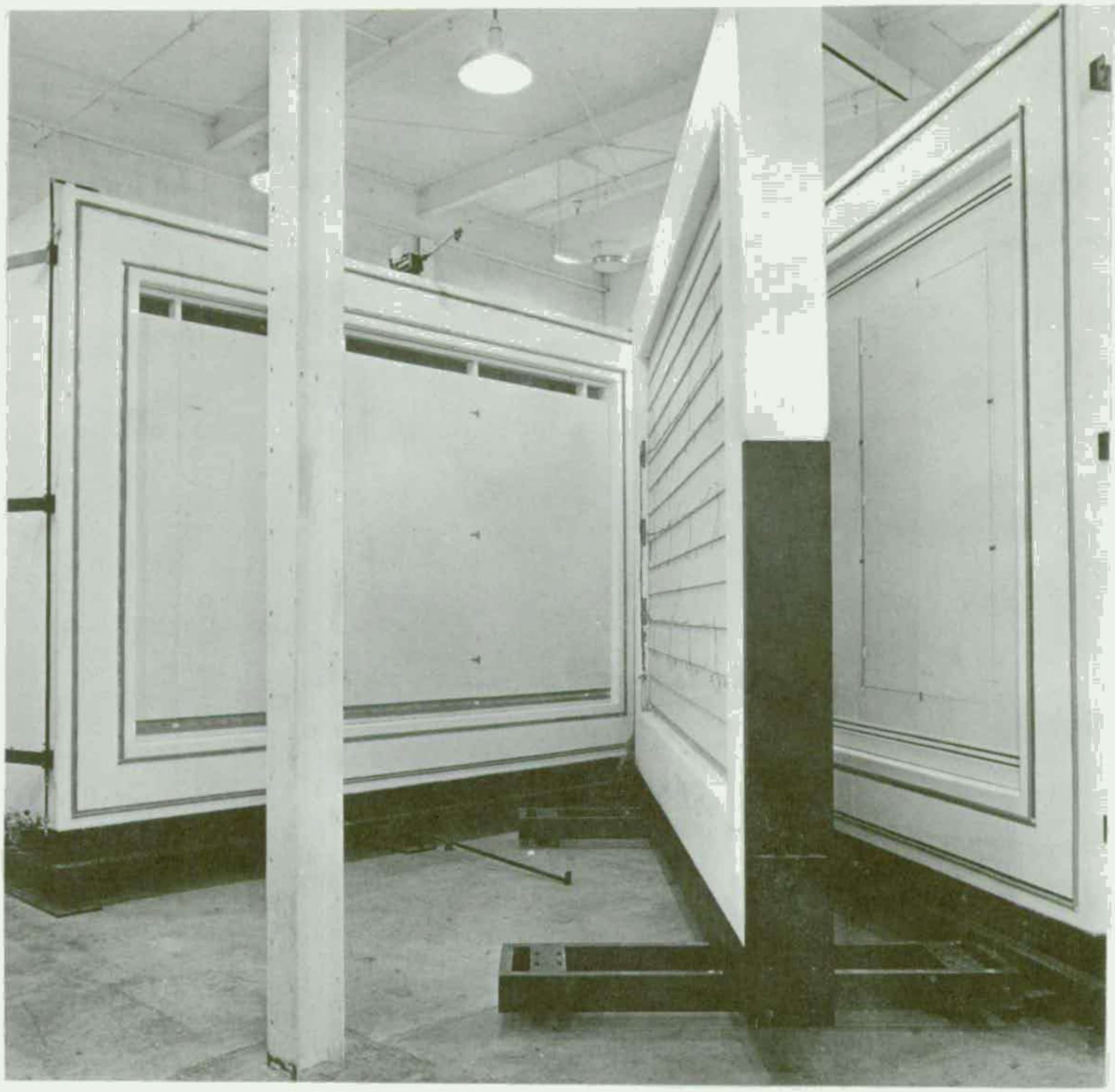

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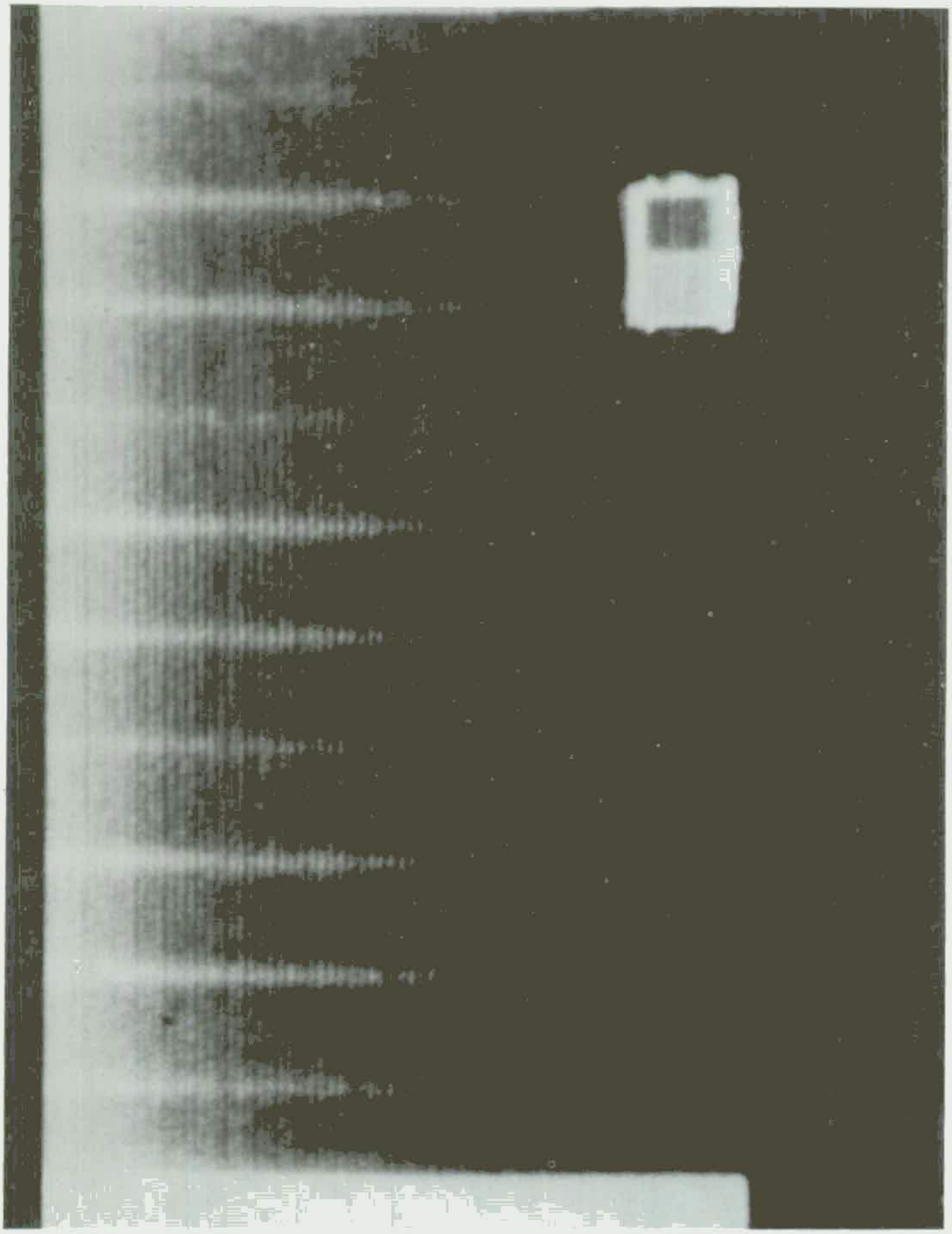

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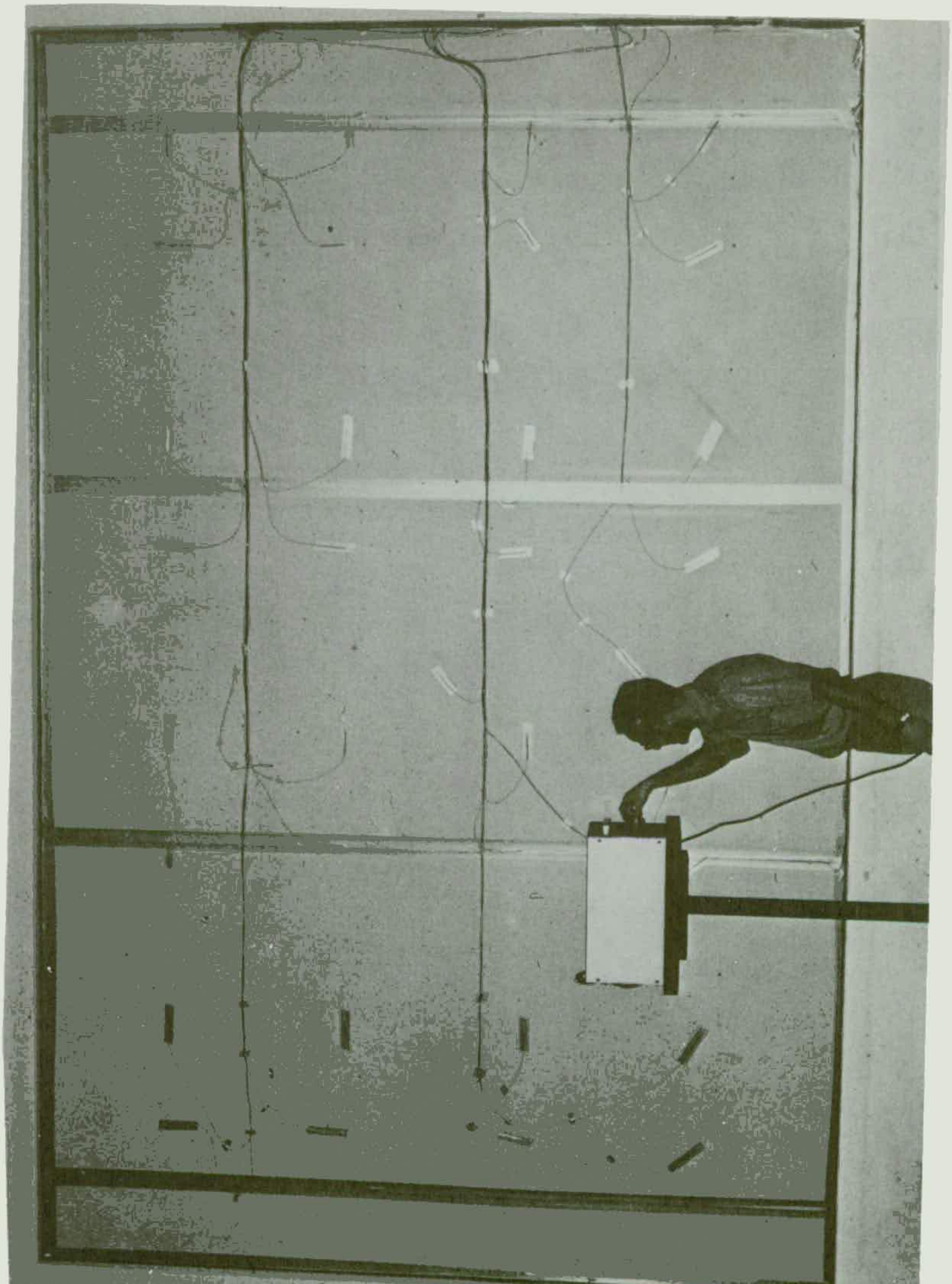

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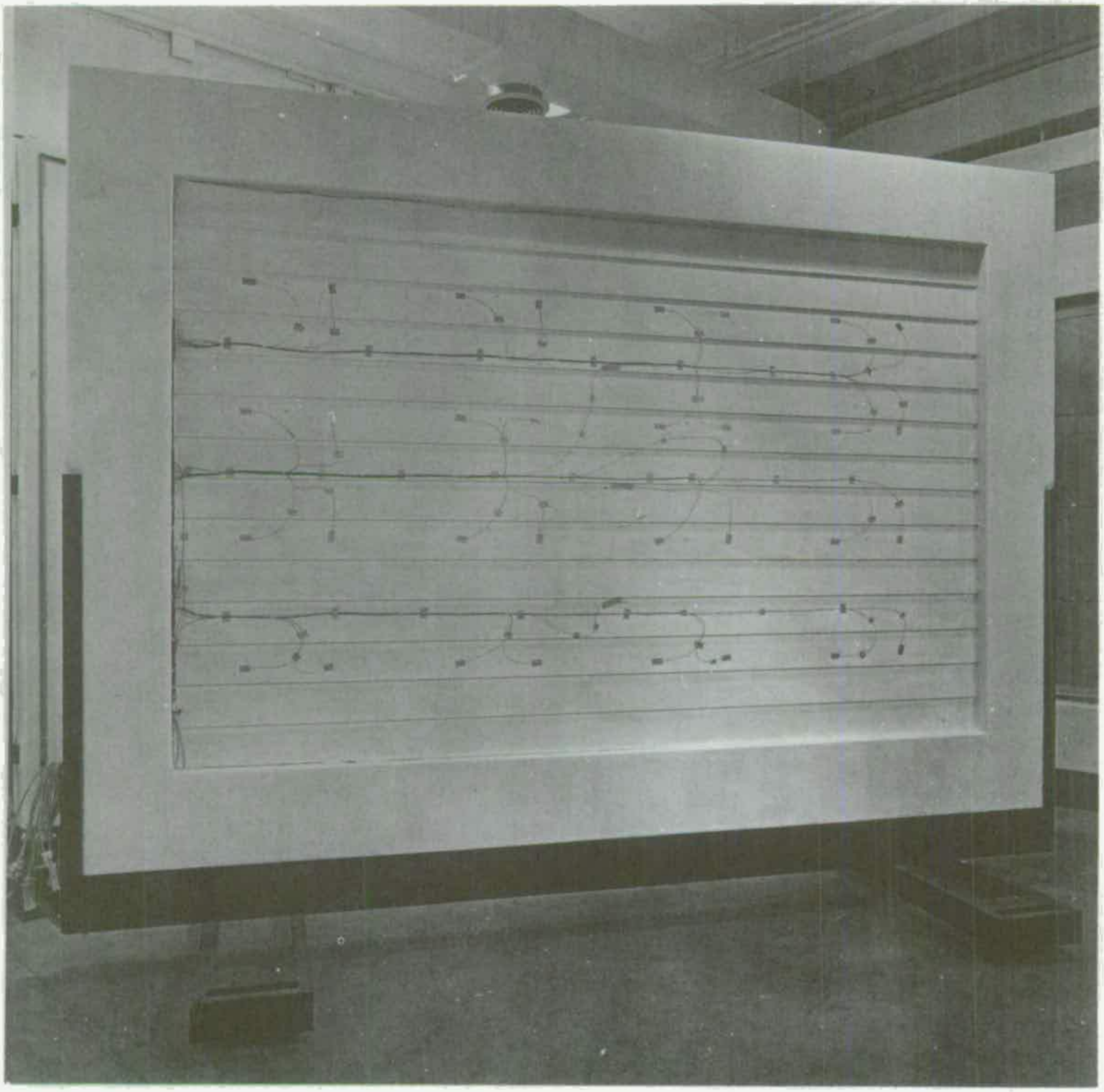

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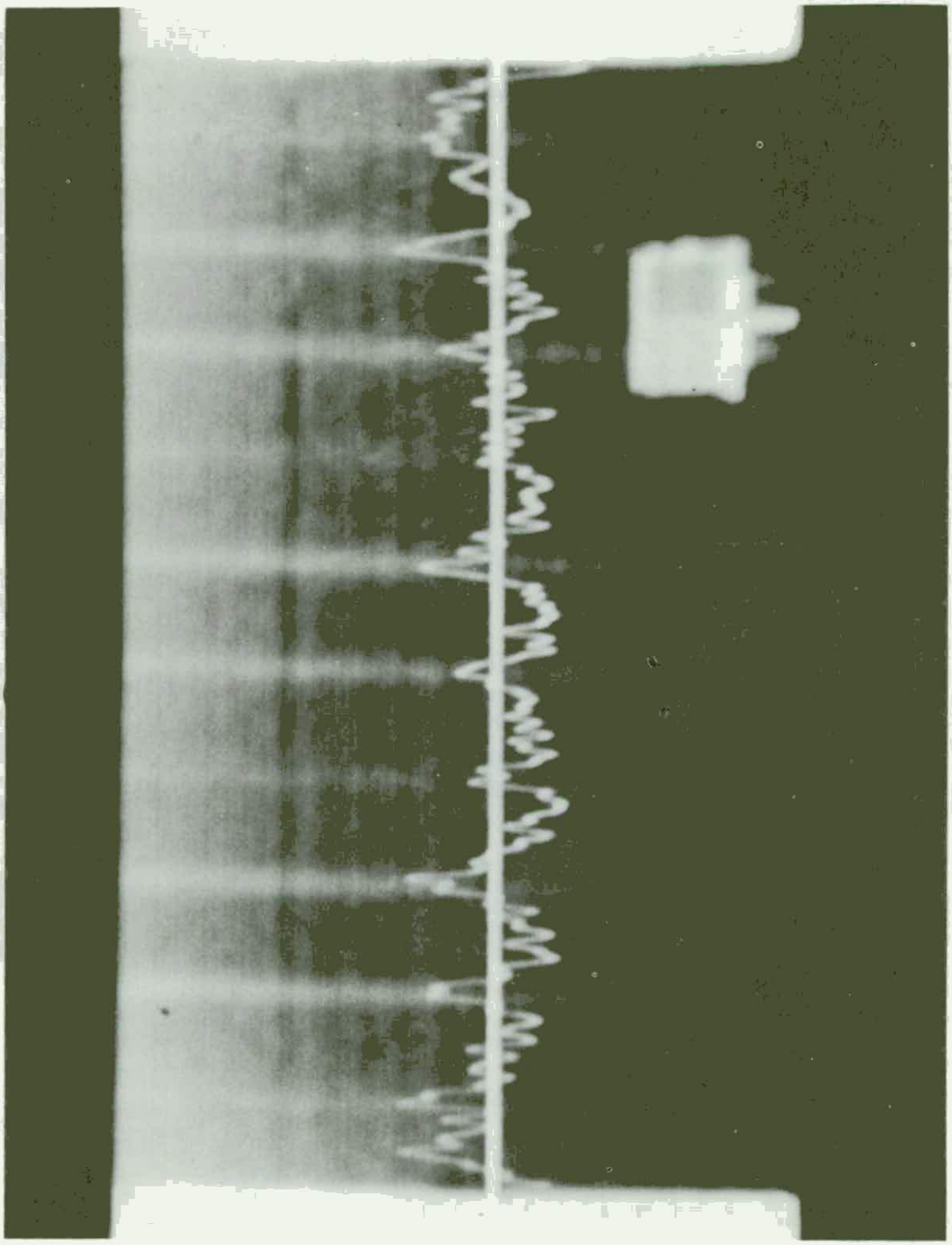

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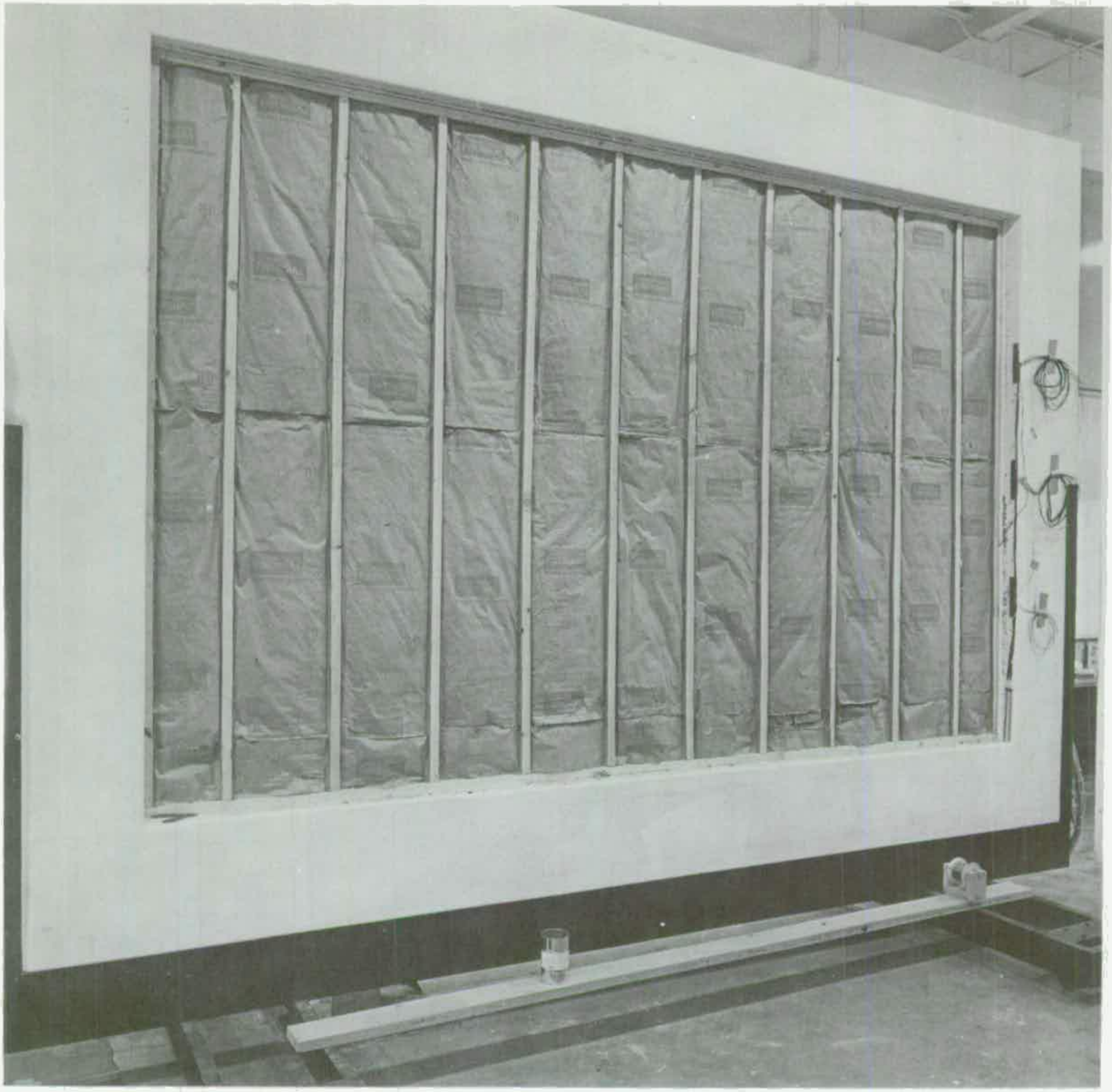

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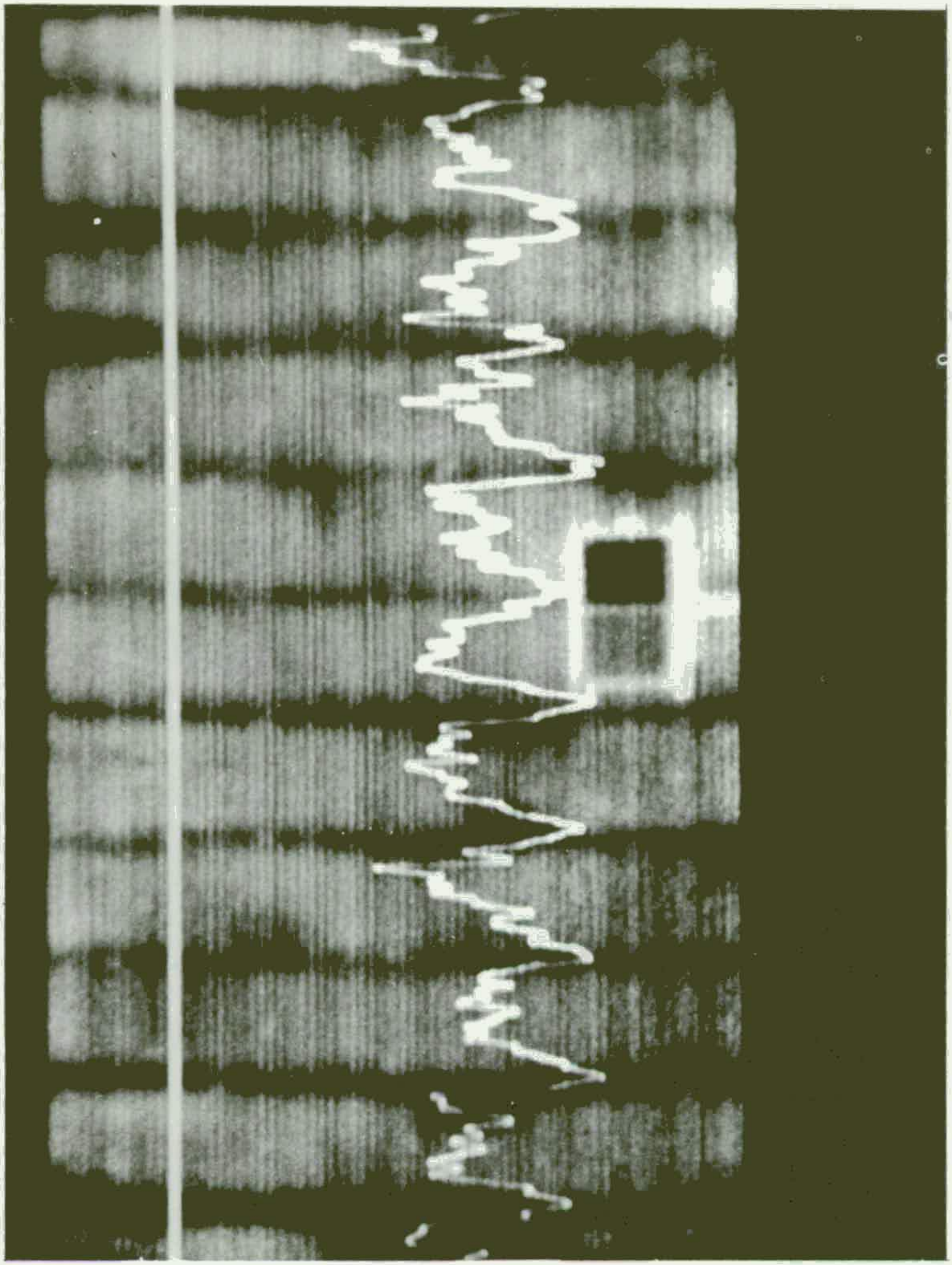

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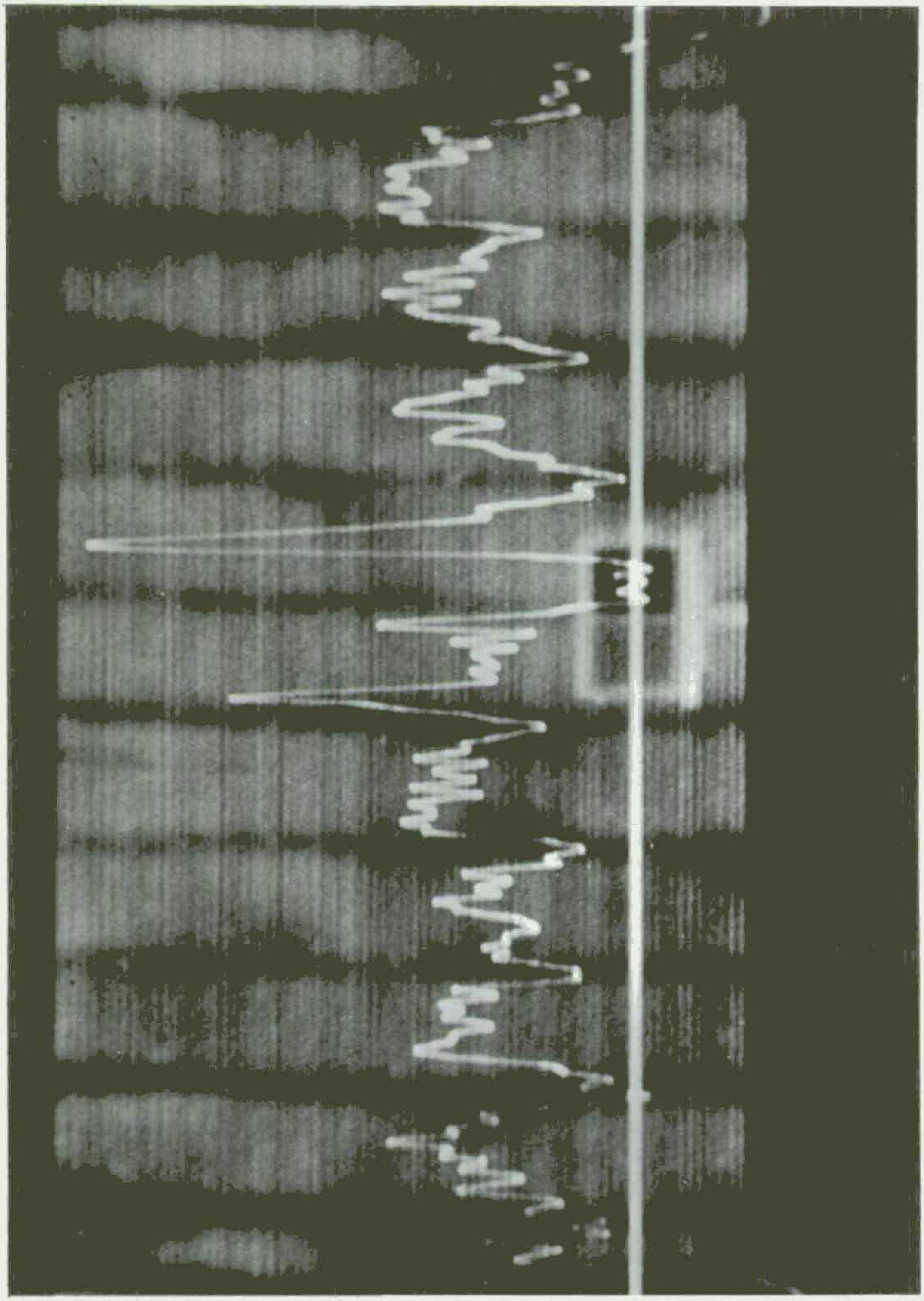

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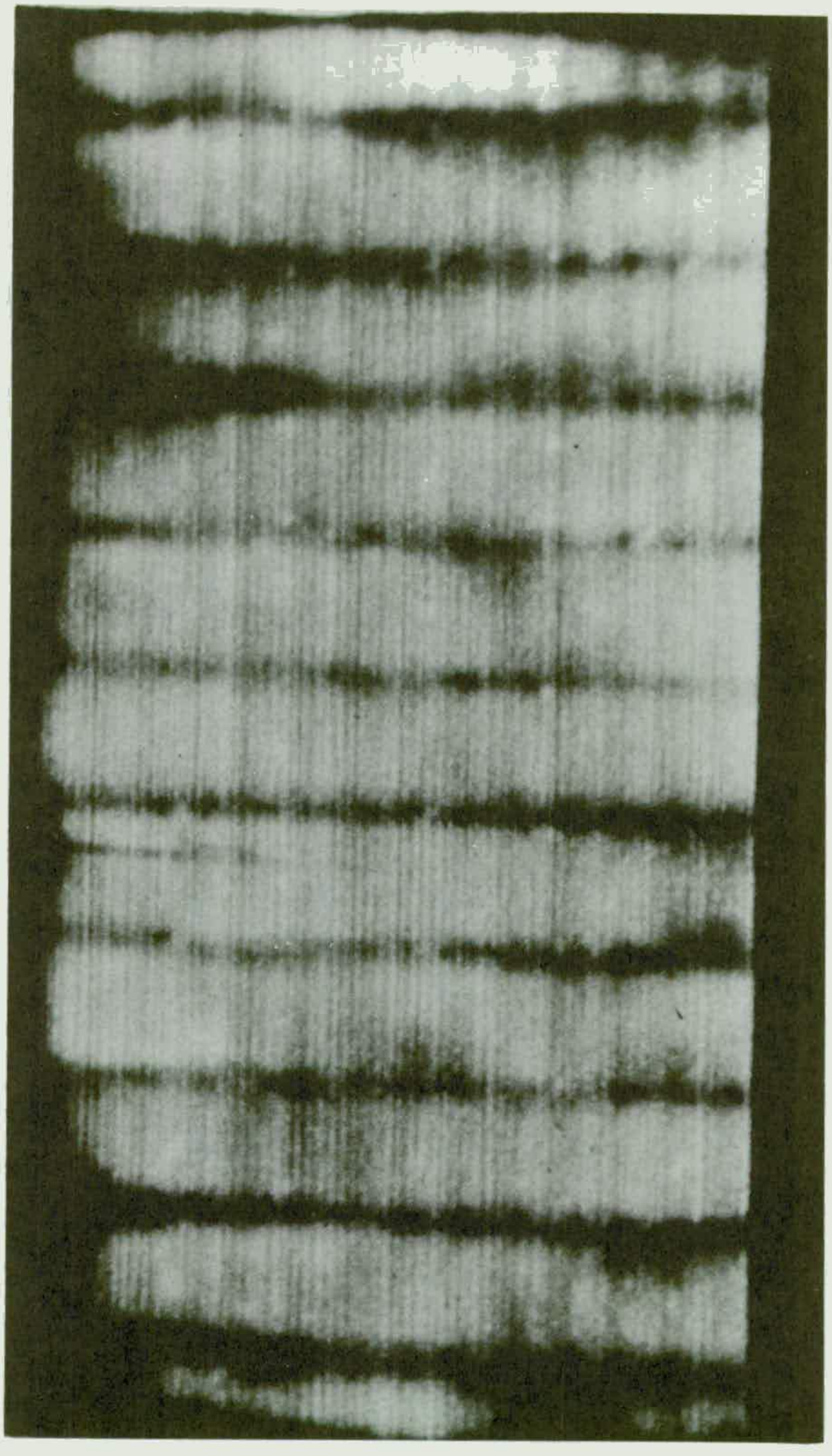

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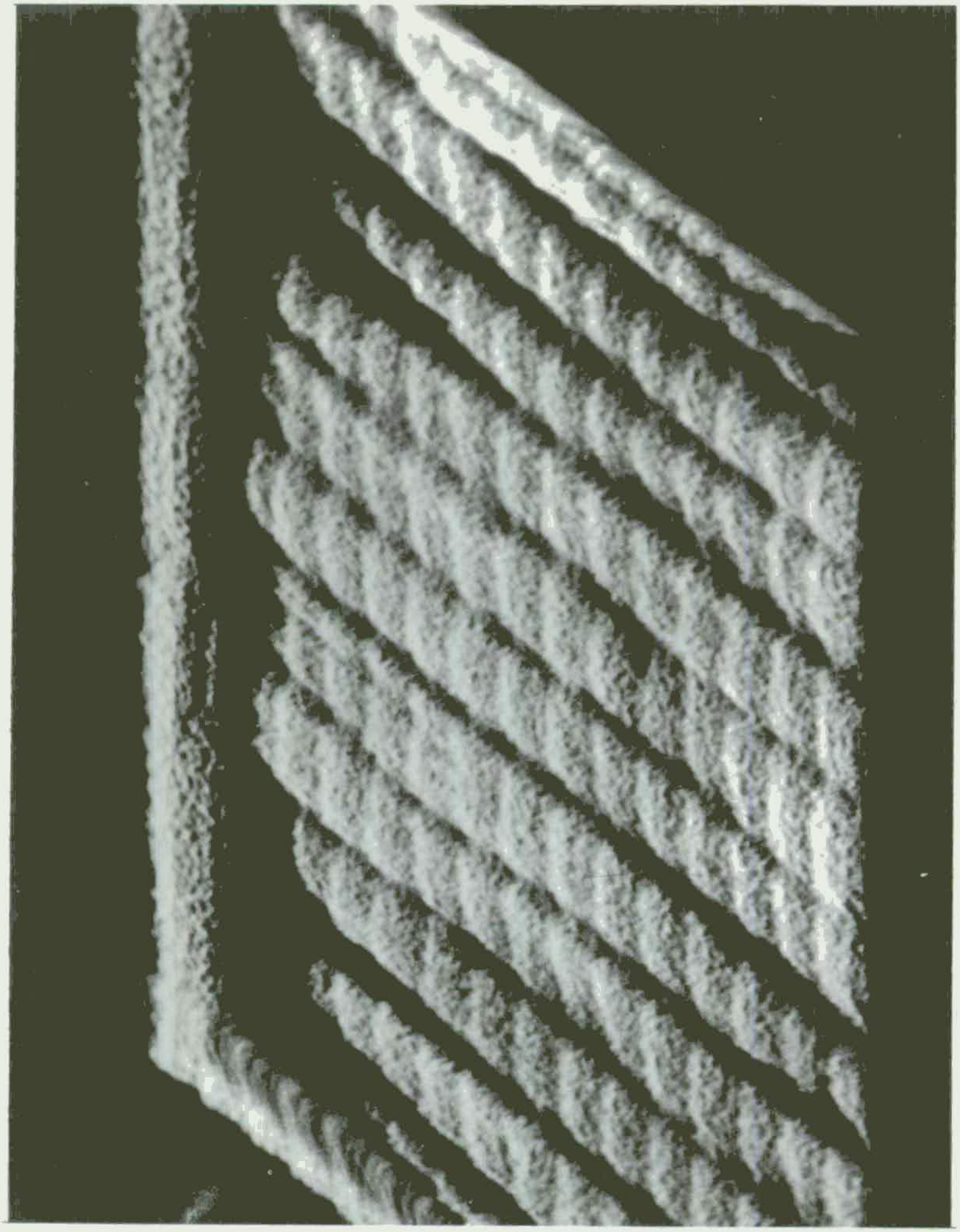

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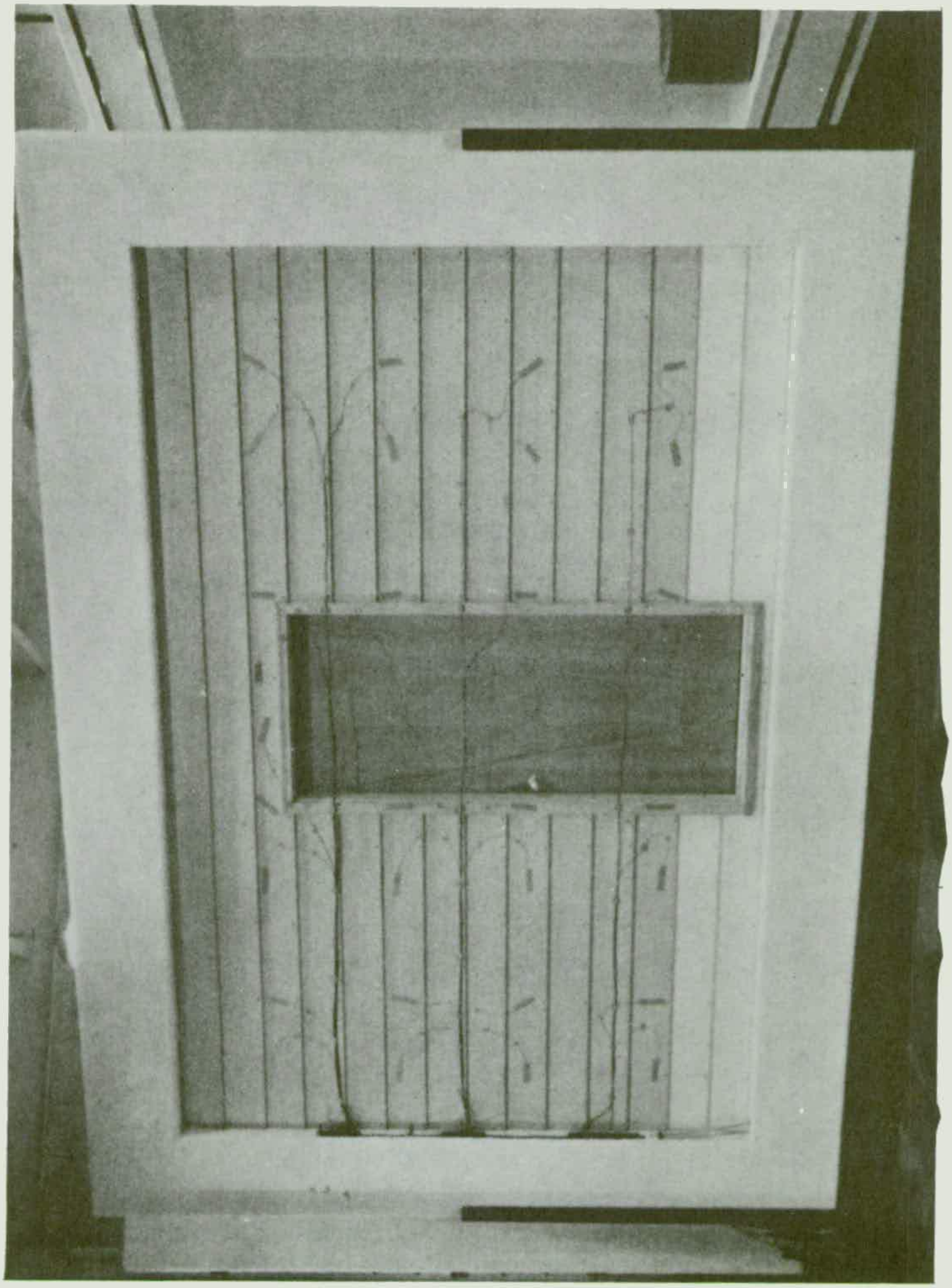
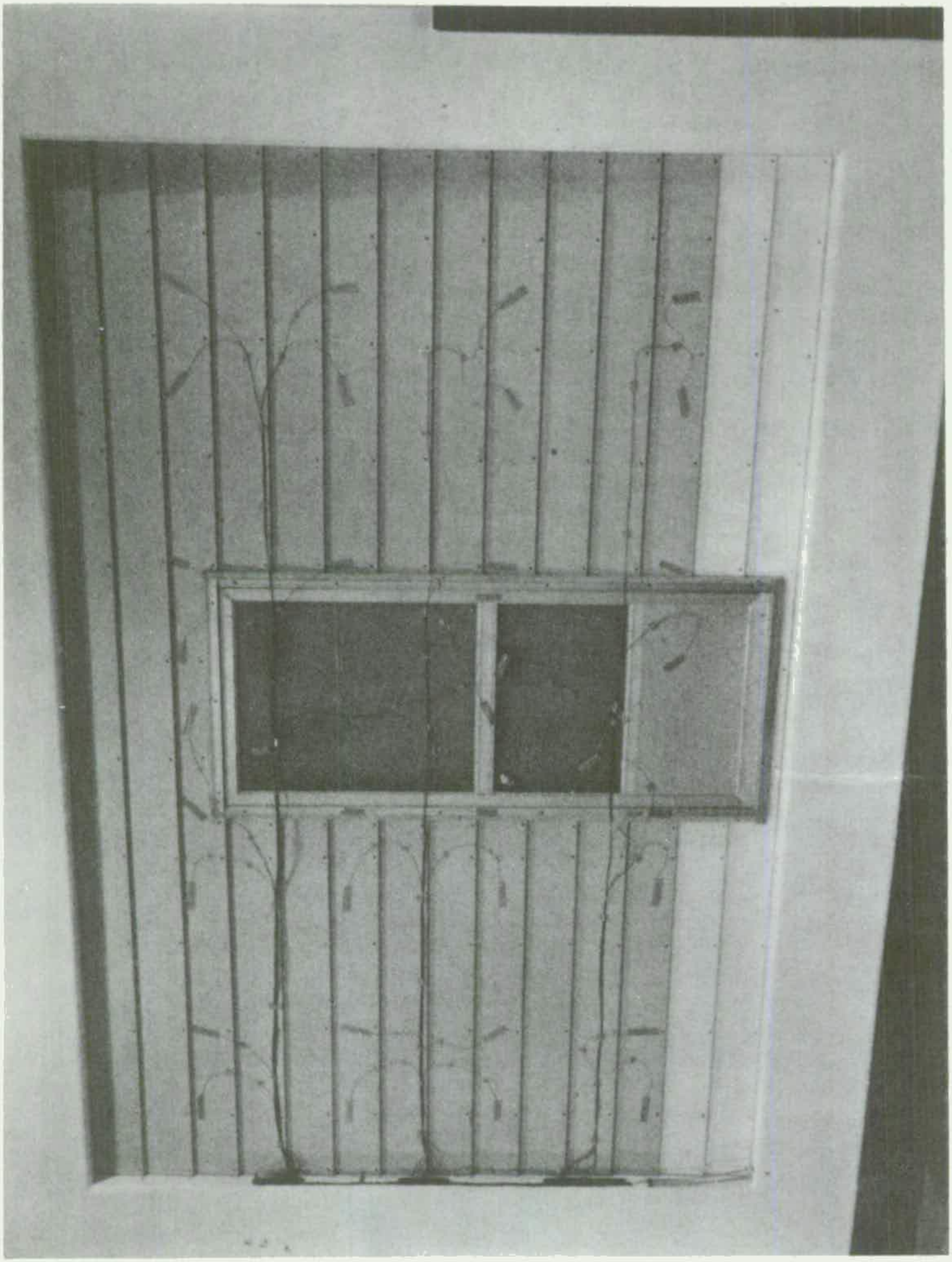


Slide 18



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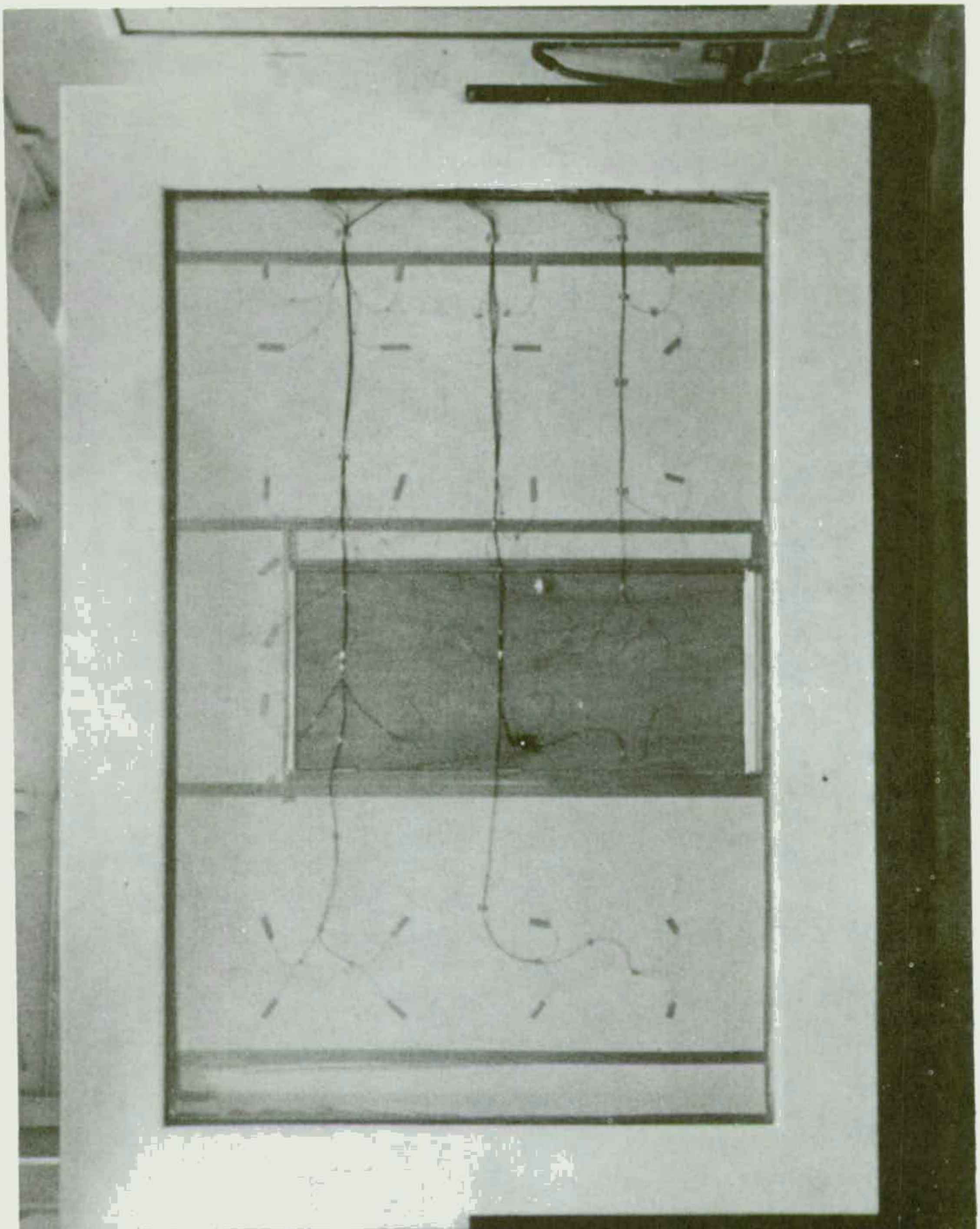

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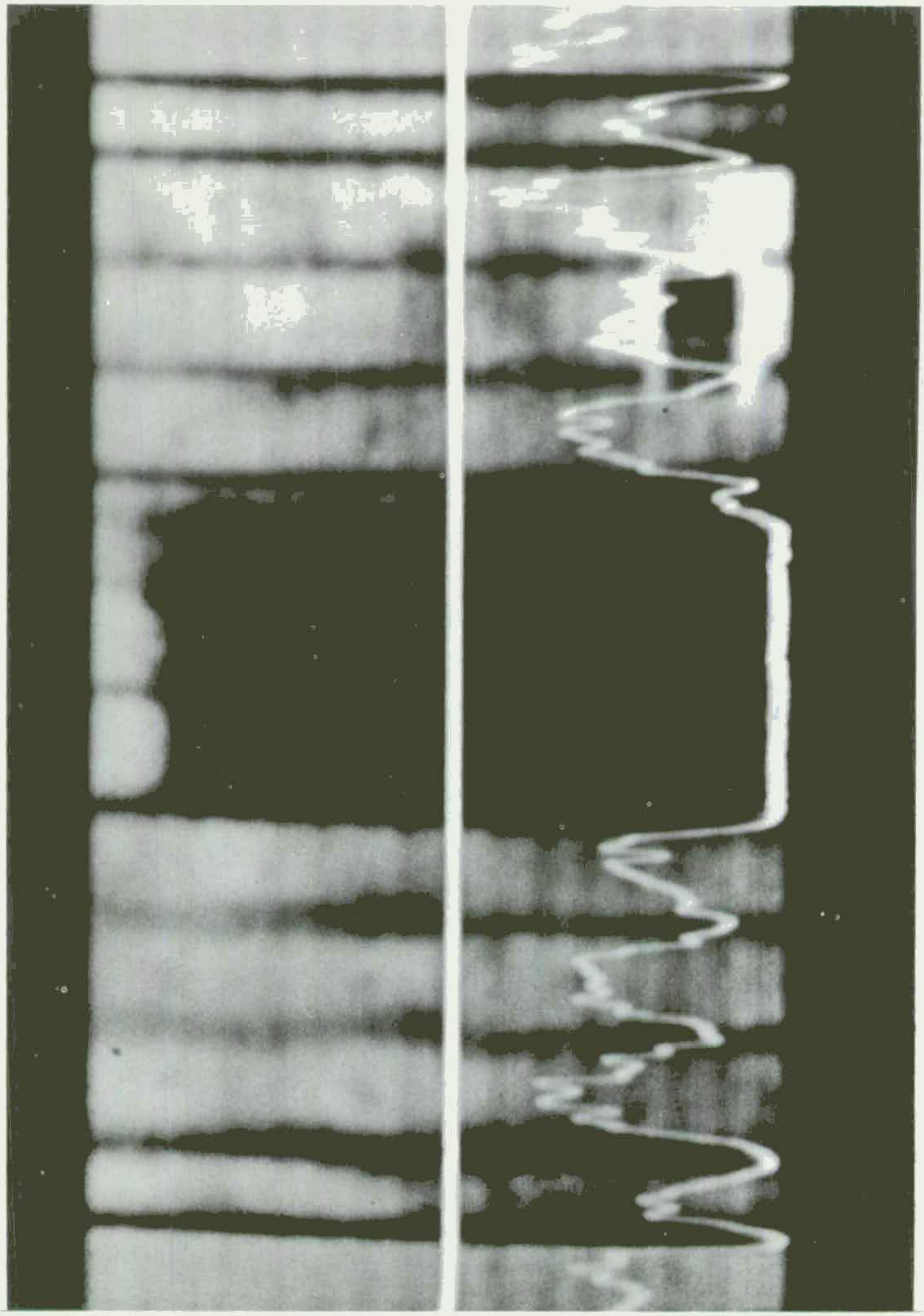

Slide 21

NEW APPLICATIONS FOR INFRARED MICROIMAGING

Herbert Kaplan
Barnes Engineering Co., Stamford, Conn.

Within the past year, several papers have been presented concerning the advent of a new device for real-time non-contact thermal imaging of microscopic targets. This device, the RM-50 IR Microscanner has since been utilized in several new and interesting areas of non-destructive testing and it is the purpose of this paper to discuss these new applications and to project some areas which show future promise.

Reviewing the development of this device, thermographs or infrared cameras measure the self-radiation from the surface of targets and convert these energy distribution patterns to visible images, generally presented on the face of a cathode ray tube. These patterns, if properly generated and interpreted, can hold the key to such sought after parameters as structural integrity cohesion, adhesion, insultaion integrity seal effectiveness and material purity and uniformity. Infrared cameras image macroscopic targets typified by spatial resolutions on the order of 0.030 inches (750μ). New developments in infrared detector technology and lens fabrication have recently made possible thermal imaging with spatial resolutions down to 10μ.

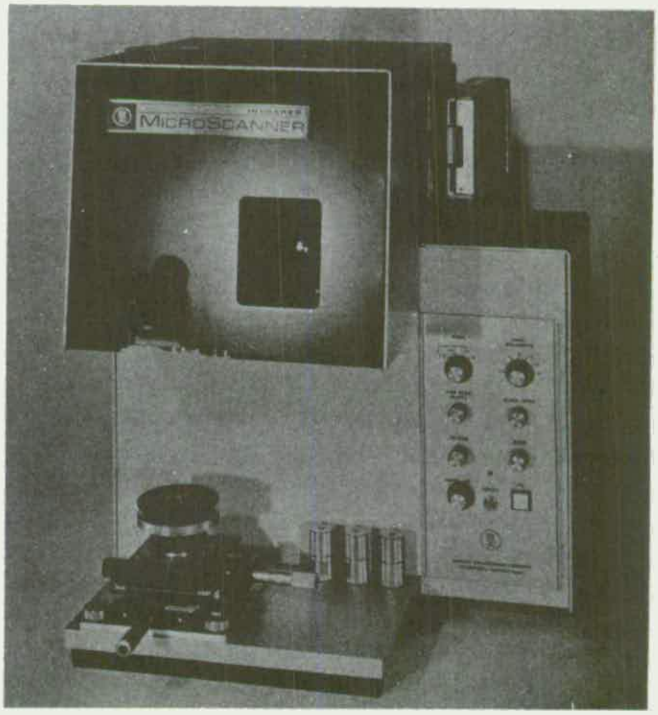

Figure 1. RM-50 MicroScanner

The Infrared Microscanner embodying these new developments is shown in Figure 1. The single benchtop unit features a micropositioning substage with four directions of adjustment, range and zero-offset controls, display mode selectors, real-time display screen and a built-in Polaroid photorecorder for making permanent records. The schematic of Figure 2 depicts the functional operation of the microscanner.

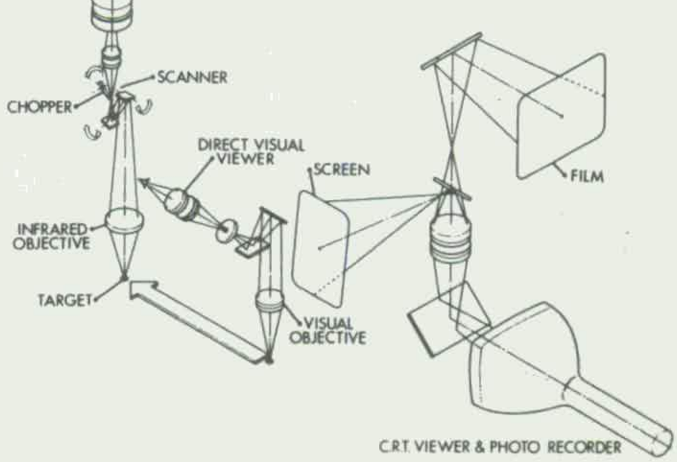

Figure 2. Optical Diagram of RM-50 MicroScanner

Tracing the schematic, the incoming radiation from one point of the target is

LIST OF MICRO SCANNER OBJECTIVES			
POWER	Spot Size	F.O.V. (Square)	Working Distance
100X	.0004″	.025″	0.3″
40X	.001″	.064″	1″
10X	.004″	.25″	4″
VARIABLE 3X or LESS	.012″(0.5mr)	.75″ (2°)	30″-∞

NOTE: ELECTRONIC ZOOM MULTIPLIES ALL POWERS UP TO 3 TIMES

Figure 3. List of MicroScanner Objectives

collected by one of the two lenses shown. For target orientation and focus, the visible lens is used in conjunction with the eyepiece. The target is positioned in X, Y, Z, and Ø until the proper orientation and focus is attained. The germanium lens is then slid into the optical path. This lens collects the infrared portion of the radiant energy and focuses it on the infrared detector. The detector converts the energy to an electrical signal which is amplified and fed to the intensity modulation circuit of the display oscilloscope. Scanning of the target is done in image space (behind the lens) where the working distance is normally large in a microscope. It is accomplished in both X and Y by means of torque-motor driven mirrors interposed in the optical path between the lens and the detector. Also interposed in the optical path is a blackened, temperature monitored tuning fork chopper, which establishes an absolute temperature reference for the system and corrects for ambient temperature drift. The scanning torque-motors are driven by sawtooth signals, the frequency of which determine the scan rates and the magnitude of which determine the scan angles. These same signals are fed to the X and Y deflection plates of the display in synchronism with the scanning mirrors so that each resolution element appears in its proper place on the display. The display image is projected simultaneously, by means of a beam-splitter, to the viewing screen and to the film plane of the photorecorder. The scanner output is normally a picture containing 64 horizontal lines repeated at the rate of one frame per second. In "High Resolution" mode it scans a 128-line picture at one frame every two seconds.

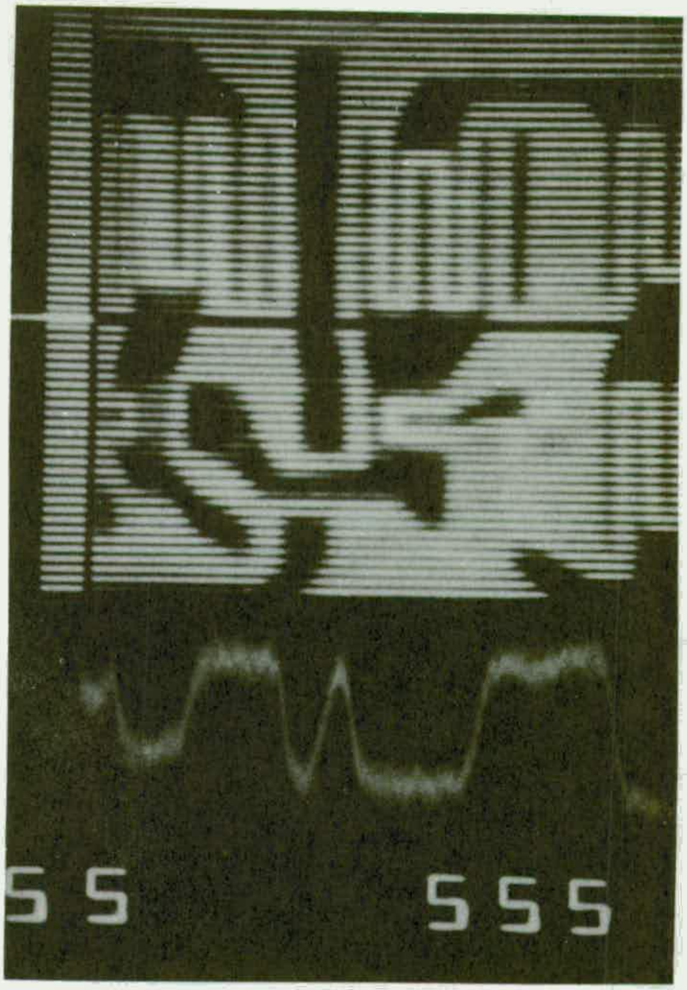

Figure 4. RM-50 Composite Display of I.C Chip

The spatial resolution (instantaneous spot size) and maximum picture size are selected by means of interchangeable objective lens sets. A table of the objective lens sets available is shown in Figure 3. Each set contains a visible and infrared lens of the same magnification mounted in a slide arrangement.

The table shows magnification, spot size, maximum picture size and working distance. The note below on "Zoom" will be discussed later. It is interesting to note that the 3X focusable objective effectively converts the Microscanner to an infrared telescopic scanner. At 30 inches working distance, for example, it scans a 0.75-inch picture field with a 0.012-inch spot size (about three times the resolution of a typical infrared camera).

Figure 4 shows a typical composite display of an energized 0.060-inch integrated circuit chip taken with the 40X objective. The thermogram is displayed in the inverted

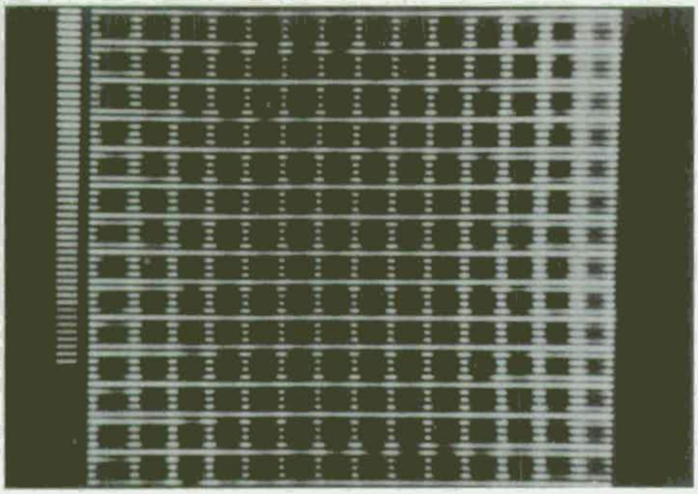

Figure 5. Microthermogram of Wire Mesh

or "black-hot" mode. (Normally, in a thermogram, white indicates higher thermal levels). The spatial resolution of the display is 0.001 inch and the frame rate is one picture per second. An amplitude presentation of a selected horizontal line is also shown. This line is selected by means of an operator control which blanks out the selected line on the thermogram and places a bright cursor adjacent to it on the display. The alpha-numerics at the bottom of the display automatically show the radiation value of the black level and the dynamic range selected.

Controls are also provided for bringing about certain other forms of display.

Figures 5 through 7 show the capabilities of the instrument in three display forms. Figure 5 shows a normal thermogram of a calibrated wire mesh with the 0.001-inch spot size, 40X objective. The wires in this mesh are 1 milli-inch wide on 4 milli-inch

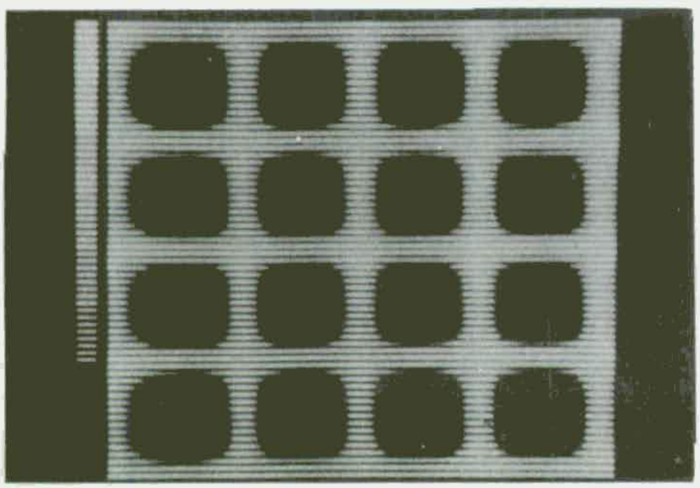

Figure 6. Wire Mesh Microthermogram with 3X Zoom

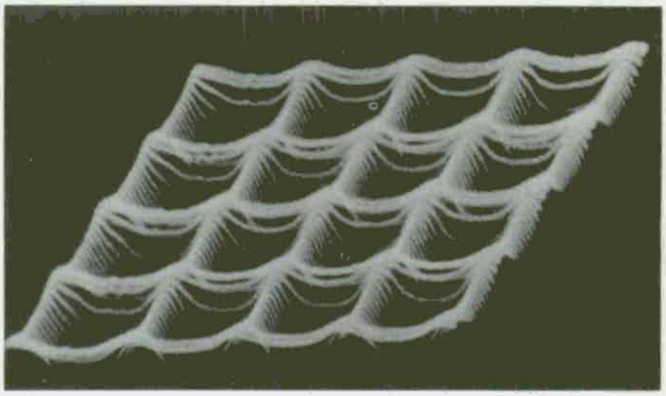

Figure 7. Wire Mesh Microthermogram with 3X Zoom and "3D"

centers. With a 64-line picture, the wires are approximately 1 scan line wide. Also shown is the 8-step gray scale which permits temperature calibration of the intensity levels in the picture.

Recall that the scan mirrors are normally slaved to the frequency and amplitude of sawtooth signals. One program for the scanning mirrors that is built into the instrument is "Zoom". This is shown in Figure 6. The scan mirrors are electrically caused to scan over a smaller target field at the same frame rate while the display sweeps are maintained at their same amplitude. The result is an apparent magnification of the central area of the target. Continuous adjustment of "Zoom" up to 3:1 is provided.

In attempting to show 3 dimensions, i.e. X, Y and video, on a 2-dimensional display, it is normally necessary to compromise one or more of the 3 dimensions. In the conventional intensity display, X and Y position coordinates are optimized, but the degree of resolution of intensity is degraded. The single line display optimizes intensity by eliminating one position coordinate, usually Y, completely. A third alternative, the "3D" display, tends to equalize the degree to which the three dimensions are compromised.

This display is shown in Figure 7. It is a 3D isometric display of the same target as Figure 6 with X, Y and Z axes. X and Y represent target position and Z represents video amplitude. Electronically, the display is generated by adding video into the Y axis. The amount of video added is adjustable by the operator, depending on target conditions.

The applications of the Microscanner fall into four broad categories.

TABLE I

SEMICONDUCTOR APPLICATIONS OF THE MICROSCANNER

I. Semiconductor Device Design (Integrated Circuits all types Memory Cores)
   a) Materials selection
   b) Studies of temperature dependence of physical properties, i.e. carrier mobility, resistivity, leakage current, and breakdown voltage
   c) Studies of temperature-associated phenomena such as second breakdown
   d) Studies of device characteristics under conditions of steady state, pulsed, and R. F. operation
   e) Provide empirical data for use with analytical studies for thermal packaging design

II. Semiconductor Device Reliability
   a) Inspection of lead bond quality
   b) Inspection of device to substrate bond quality
   c) Inspection of metalization quality

III. Design of Thin Film Resistors

IV. Hybrid Device Packaging Design & Reliability Studies

V. Solid State Diode Emitters & Laser Design & Performance Determination
   a) Studies of output structure (intensity, distribution, etc.)
   b) Packaging design
   c) Studies of temperature dependence on threshold currents, output power and emission wavelength

1. Design of Semiconductor Devices
2. Optical Materials Studies
3. General Materials Evaluation
4. Medical and Biological Studies

As is well known, conventional microscopy is used to examine, under visual illumination, microscopic detail in both miniature objects and small portions of larger objects. If the object is opaque to visible light, only the surface can be examined. If it is desired to detect some internal irregularity of inclusion, the object must transmit visible light. The development of an infrared Microthermograph greatly extends and expands these areas of application by presenting a thermal image of microscopic objects. Normally, no illumination of any kind is necessary for these measurements since the radiation is self-emitted. In addition, however, it is now possible to transmit infrared energy through materials which are opaque in the visible, but transparent in the infrared and to obtain, thereby, images of internal

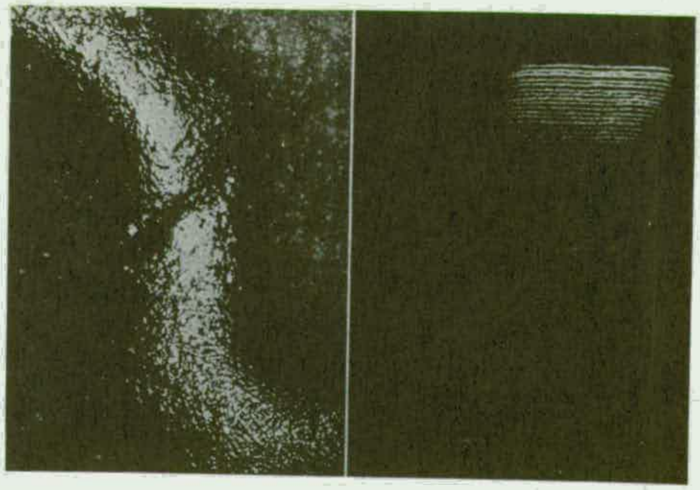

Figure 8. Microthermogram of cracked Micro Circuit Substrate

details. An important class of such materials is used in the construction of semiconductors and microcircuit devices and consists principally of germanium and silicon. These materials, as well as numerous others, are also used in the important area of infrared refractive optics.

Table I lists numerous applications in 5 classes of Category I, Design of Semiconductor Devices. The powerful combination of temperature measurements and transmitted images provides considerable information about a device under test and any potential faults or defects. In many cases absolute temperature is not as significant as temperature distribution. For example, the location and analysis of cracks in microstructures is illustrated in Figure 8. Here the barely visible substrate crack in the photograph is seen to result in an appreciable thermal discontinuity on the 3D mode microscan. The crack is approximately 0.001 inches (24 microns) wide.

For transmission measurements, it is necessary to illuminate the sample from beneath. Since the transmission is often quite low, a useful high intensity source is a small helium-neon laser operated in the infrared at 3.39 microns. It is important to keep in mind that the electrical properties of semiconductor materials are closely related to their optical transmission and emissivity properties in the infrared.

Table II lists some of the applications in Category II, Optical Material Studies. Infrared optical materials are difficult to inspect by conventional means. Furthermore,

TABLE II

OPTICAL MATERIAL STUDIES OF THE MICROSCANNER

I. Determination of uniformity of infrared transmission for materials and components

II. Studies of internal irregularities, inclusions and scattering centers

III. Studies of the thermal change in the non-dispersive infrared refractive index of optical materials

IV. Studies of thermal characteristics of optical components for transmission of high energy densities, i.e. laser optics

they are more subject to a variety of internal non-homogeneities and defects than conventional optical glass. These are virtually impossible to detect without some form of infrared scanning test. In addition to transmission measurements, thermal properties are also sometimes important. For highly sensitive infrared radiometers, refractive optics should be temperature controlled and uniformly heated. Thermal properties of these elements can also at times indicate other potential defects such as incipient cracks (see previous Figure 8). High energy laser applications also place thermal stress on optical elements.

An example of this category is illustrated in Figure 9 where two germanium flats are compared for transmission characteristics. The uniform thermal source placed behind the two samples assures us that the thermogram is a true indication of the comparative transmission of the two samples. This thermogram was taken using the 3X focusable objective at a distance of about 30 inches from the target. The total field, then, is 0.75 inches square.

Table III lists applications of the Microscanner in Category III, General Materials Evaluation (nonoptical). It is known, for example, that segregated areas in titanium evidence a marked change in emissivity in the infrared. Titanium is used as structural material in high temperature, high stress conditions such as turbine wheels.

An example of on-line testing for structural or electrical flaws is illustrated in the microscan sequence of Figure 10. Of a

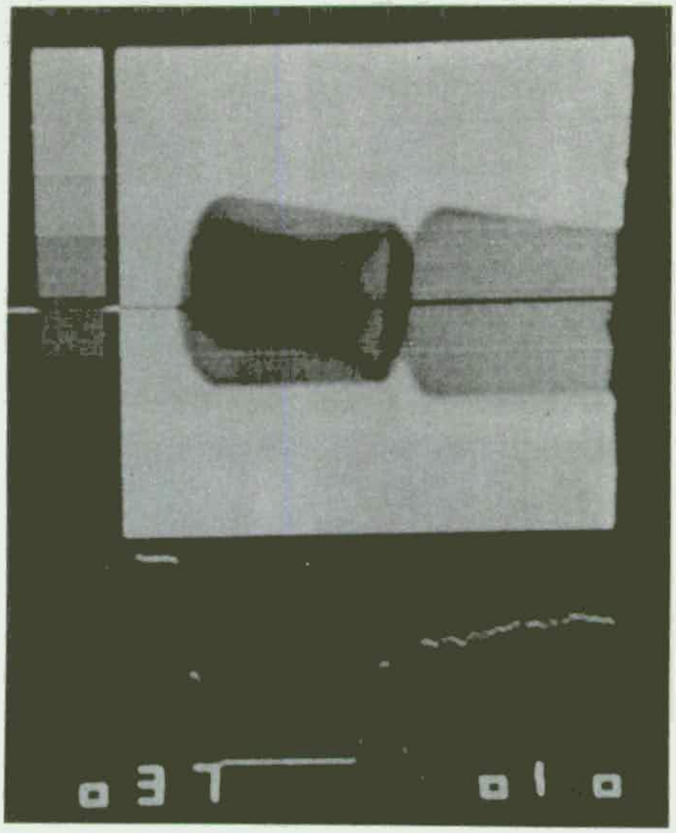

Figure 9. Comparative Transmission of Two Germanium Samples

sampling of microminiature indicator lamps, most appeared as in (a) with a small fraction of rated voltage applied to the filament. One of the samplings appeared as in (b). These

TABLE III

GENERAL MATERIAL APPLICATION OF THE MICROSCANNER

I. Metallurgical & Material Surface Properties
   a) Inspection of titanium components for segregations created during welding and manufacturing operations
   b) Studies of optical surfaces (Metallic) for laser damage
   c) Detection of surface cracks in small castings such as turbine blades

II. Thermal Characteristics of Structural Materials
   a) Inspection of substrate materials for uniformity of conductivity
   b) Studies of materials for high temperature electrodes

III. Temperature Profiles of plastic and other fibers

IV. Thermal Profiles of Miniature Rotating Parts

V. Inspection of Miniature Components During Vacuum Welding & Brazing Operations

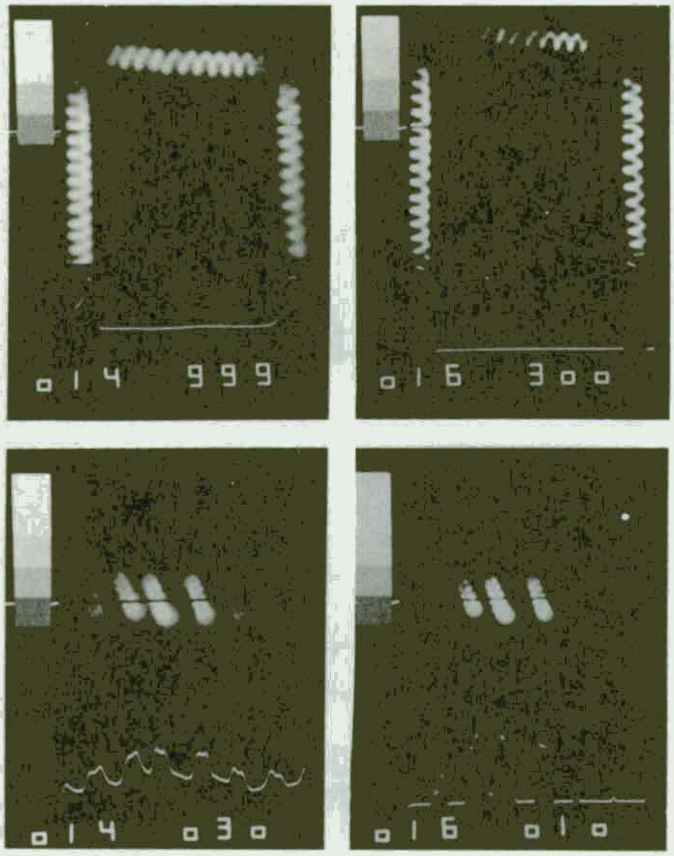

Figure 10. Microscan Series of Miniature Lamp Filaments

were taken using the 40X objective with no "Zoom" so that the picture size was about 0.060 inches square. To improve spatial resolution, they were taken in the "high resolution" 128-line mode. The suspect center segment of the non-uniform sample was examined more closely by applying "Zoom" and moving the single line cursor over the area of interest as shown in (c). Finally an increase in sensitivity setting and a shift in black level setting allowed the filament segment with non-uniform resistance to be seen as illustrated in (d).

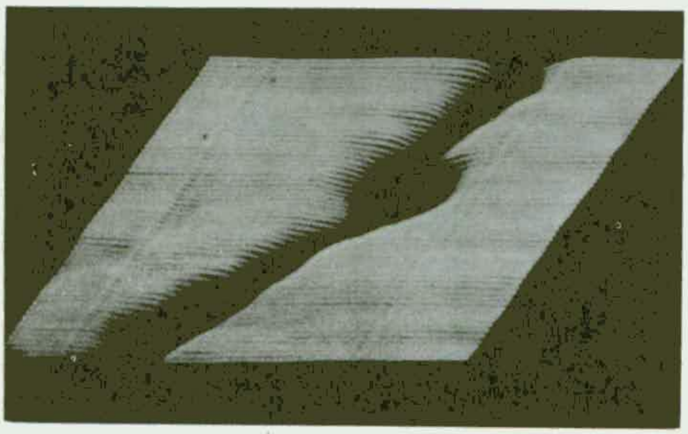

Figure 11. 3D Display of 0.002-inch Wide Turbine Blade Crack

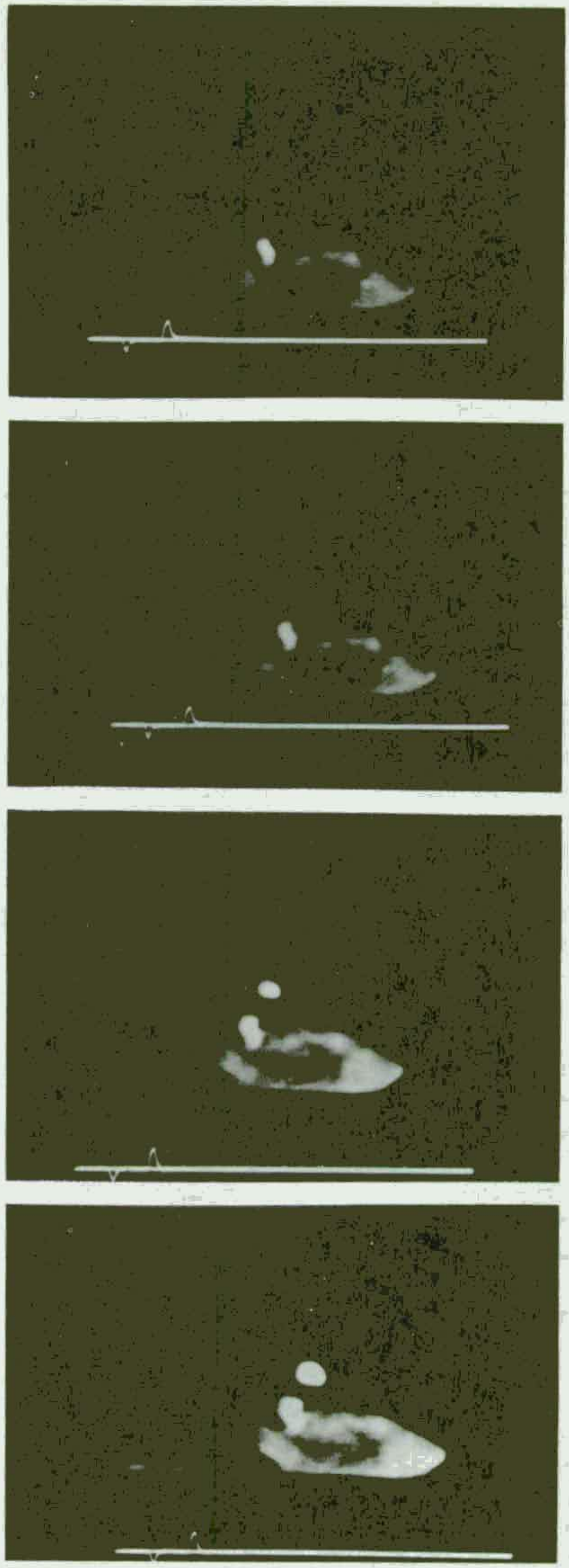

Figure 12. Thermogram Series of Laboratory Rats Subjected to R F Radiation

Detection of a crack in a steel cast turbine blade is shown in Figure 10, again in the 3D display mode. This crack was only

TABLE IV

MEDICAL AND BIOLOGICAL APPLICATIONS OF THE MICROSCANNER

I. Medical Studies
   a) Eye examinations, including glaucoma
   b) Dermatological examinations
   c) High resolution thermograms under open surgery using the Microscanner infinity or telescopic objective

II. Biological Studies
   a) Insect physiology
   b) Bacteria culture growth
   c) Plant development

0.002 inches across and was extremely difficult to detect visually.

It should be pointed out here that the image is a thermal one and should not be confused with the visible shape of the crack. The image actually displays the thermal effect at the surface of the crack and is an indication of the thermal interruption in the structure.

The final applications category, Medical and Biological Studies, is one in which relatively little work has been done to date. There are, however, strong indications of great potential in this area. An example of that potential is illustrated in the sequence of Figure 12 in which a laboratory animal was subjected to increasing, nonlethal doses of RF radiation. This series was not taken with the Microscanner, but with a Macroscanner at the shortest possible working distance. Future work will be done in this area by the Environmental Protection Agency using the Microscanner to improve the spatial resolution. These thermograms were taken at 30-second intervals, and no noticeable increase in internal temperature was recorded during this time. It can be seen, then, that the Microscanner will find applications where fast changes in skin temperatures need to be measured and recorded.

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THE ROLE OF NON-IMAGING SENSORS FOR CIVILIAN APPLICATIONS

Thomas Limperis, President
Sensors, Inc.
Ann Arbor, Michigan

To begin with I would like to ask some questions of the audience if I may. First of all, how many people do we have in the audience that are vendors of infrared equipment and/or infrared services? Would you raise your hand? Clearly this group comprises 99% of the total audience. In view of this, is there anyone in the audience that has the courage to admit openly that they are buyers of infrared equipment? Please raise your hands. Oh, apparently we do have some.

What I have to say this morning is slanted quite a bit differently than what you have heard from the other speakers. Perhaps this is a good thing for this particular audience. I am going to consider three questions. First, "Is there really a market for infrared technology in the nongovernment sector?" Second, "If there is, is it big enough to interest you and me?" Third, "If that market is substantially unexploited right now how in the devil should we go after it?" I'm going to use some terminology and some facts and ideas and describe some of my experiences in a way that may be somewhat abrasive to you. If it is, remember I am doing this on purpose, hopefully it will raise some questions and comments that we can discuss in detail during the panel session this afternoon.

I put together a view graph that I think summarizes reasonably well what the infrared equipment market is today and what it

might be in the future. I've left out of this the market for infrared imaging instrumentation. The title of this view graph really should be "Non-Government Infrared Market for Non-Imaging Systems." I think the first obvious thing that should strike you if you are an infrareder and most of you are, is that the infrared spectrophotometer is the first real manifestation of a commercial infrared product that is not sold to the military in significant quantities and is used mostly by industry. By examining the annual reports of companies that sell spectrophotometers and by making some value judgment as to what percent of their sales is derived from spectrophotometers (I'm talking about the world-wide market not just the U.S.), I estimate that today's annual sales of infrared spectrophotometers are about thirty million dollars. The market will remain substantially the same and might even increase a little bit in the near future. The second item on the view graph which is probably the second manifestation of infrared technology in the industrial market is the temperature measuring radiometer. This device can be pointed at an object and it can measure the average temperature of the viewed area. My estimate includes the sales o Barnes, Ircon, Sensors, Inc., Rayteck, Williamson and other companies around the world. These sales are about ten million dollars. This figure may be too low by a factor of two for both current and future sales. The third market is one that is just beginning. It is the auto emission analyser market. These devices,as you probably know, are used during auto tune-ups to minimize CO and CH_x from the exhaust for pollution abatement purposes. It is really sort of an offshoot of the spectrophotometer.

Today's annual market for this type of equipment is roughly two million dollars. Based on surveys made by the Environmental Protection Agency, in the future the market will be about twenty-five million dollars annually. I think that estimate is conservative. Fourth on the list we have industrial gas monitors, devices that are used in industrial plants to monitor the concentration of effluent gases or the concentration of gases in production processes. The market size is now about five million dollars annually and should build up to about twenty million dollars annually in the next four years.

An interesting and important point to make here is that the first two items on the first viewgraph have a cost benefit that the user can clearly identify. The customer can be sold on a cost savings basis. That is not true of the next three devices - the auto emission analyser, industrial gas monitor, and tire defect sensing system, where the customer is not saving money by buying your equipment. The markets for this kind of equipment are developing because of existing and forthcoming government regulations for meeting certain standards. Markets like this are difficult to schedule because the timing is primarily based upon the timing of government legislation. Quite a few high technology companies have "bitten the dust" because of premature efforts.

The tire defect sensors is also a new market that is beginning to unfold. The current annual market is about one million dollars. In the future the market is expected to be about five million dollars. This is a small market that by itself is not worth the time and trouble from a business point of view. Next we have the intrusion alarm, and by that I mean devices that can sense the

presence of undesirable persons on the premises and ring an alarm or perform some other function to cause the person(s) to leave so that the facilities, equipment, and / or residents can be protected. The market today for infrared type intrusion alarms is two million dollars, (i.e. two million dollars of infrared intrusion alarms are now sold annually.) My feeling is that the potential market for these devices over the next three to ten years is twenty million dollars annually. The security market is very large. Today it is being inundated by acoustic and microwave sensor systems. However, the false alarm rates are inordinately high. I believe that from the market analysis we have done so far we have determined that a passive infrared system is pretty much the way to go. False alarm rates should be reduced significantly. If I am correct in my analysis and if the price for passive infrared units can be as low as $100 each, the potential market is enormous. I think an estimate of twenty million dollars a year is conservative.

Now at the bottom of this viewgraph I have listed some things which are not being marked and sold today. These potential markets are quite large. I'm going to talk about these new markets and then discuss a few applications which we at Sensors have worked on and then tell you a little bit about our approach to new product development.

The infrared fire suppression system consists of a fast infrared flame sensors and a valve actuation that releases a flame suppressant gas to put the fire out fractions of a second after

it started. There will be a growing market for this type of infrared device, reaching at least five million dollars per year in the future. It is possible that this market could be as high as twenty million dollars annually for the sensors alone. This application has been awaiting a sensors for a long time. Why haven't infrared companies moved into this area sooner? The infrared equipment companies considered the problem only after a military requirement was established. That doesn't speak well for our awareness of the non-government sectors' equipment needs.

Infrared pest control devices are next on the list in viewgraph one. The first comment I expect from you when you see that is "my god, how can you use infrared to control insect pest populations." The reason I put this on the list is to show you the subtle and interesting ways that infrared can be put to use. This market is enormous, and the economic benefits for such devices are staggering. The lost of crops to insect pests is estimated to be in the billions of dollars annually. A solution like this could easily justify the enormous budgets that are pouring into government supported infrared programs. We at Sensors did a study about a year ago for the Department of Agriculture where the objective of the study was to find out the insects responsivity versus wavelength for night flying moths which are most damaging to agronomic crops. In that study, we found that adult insects of this type that fly at night and whose larva do the actual damage interact with electromagnetic radiation in the infrared spectrum. You've all observed the effects of insect attraction to porch lights. Lots of bugs come out and fly around the bulb.

That's a pretty simple experiment and I am sure everybody has observed it. For the electromagnetic spectrum beyond the visible region then the experiment becomes a little more difficult. I'm not going to spend all my time telling you the details of the experiment, except to say that we used descrete sources and blackbodies to determine insect spectral response. The descrete sources included solid state and gas lasers. The best results were achieved with a cyanide laser at 337 microns. In fact the response of the insects at that wavelength was a factor ten times greater than test results using ultraviolet light. These experiments were performed in a cage which is big enough in diameter so the insects can fly pretty well. The electromagnetic radiation source is directed from one end. Then freshly emerged moths (virgin males) are put in to observe their response to the EM radiation. Shortly thereafter, virgin females are put in to determine their response to EM radiation and to see whether the male - female attraction has been affected. When a hydrogen cyanide laser of 5 milliwatts was used they all rushed over to the end of the cage containing the source. Measurements were made of how much time it takes for the bugs to go from one end of the cage to the other. This number is a measure of the degree of attraction. These remarkable results have prompted quite a few questions. From the scientists the questions revolve around "why does it happen and how does it happen?" From the businessman the basic questions revolve around feasibility, costs for development and market potential. No questions have been asked from the old time infrared equipment companies.

The results were published over a year ago in the journal Nature. One final point on the experimental results, we took some antennas from these insects and cut them up carefully to measure the geometry, and dielectric constant, and then calculated their spectral response using basic antenna theory. A plot of that response versus wavelength shows a sharp peak at 350 microns.

A major source of problems in industry is human error. These errors decrease the quality and reliability of the product and also increase the cost considerably. For example, if you send a man out in the yard for some steel stock to manufacture some parts in your plant, and you tell him to bring Steel Type #137, he'll often come back with Steel Type #136. The error appears to be harmless, but careful analysis of the real situation shows the enormous costs produced by these errors through auto recalls, accidents with loss of life, etc. So this industry would like some quick method for the inspector to use that tests the steel stocks in the yard to verify the label. It seems like a silly, simple problem that isn't worth the instrument designers attention, but I guarantee you it's not. I think the possible market for material verification is enormous. If you can save twenty million dollars a year it's quite a lot of money.

The last item on viewgraph one is a real important application for an EM remote sensor. There aren't any effective useful devices available to the industry today. There is a mechanical profilometer with a stylis like that of a record player. It's usually pulled across the surface of a machined work piece. It will tell you what the peaks and bumps are but usually the diameter of the

stylis tip is about ten times as large as the surface wiggles that the QC engineer is interested in. This is a horrible problem, in the jet airplane industry for example, a prediction on the wear of a part is based almost entirely on the composition of the part and surface roughness of the part. The QC engineers in industry try to predict their needs in a particular application but just can't do it, because basic testing devices are not available. Therefore, the QCengineer chooses a surface finish that is smoother than he may really need just to be on the safe side. Usually the finish selected can't be measured anyway so if there is a catastrophy he can always point out that it wasn't measured correctly. I am constantly asked when I tour through the Society for Non-Destructive Testing on my lecture tour through Pennsylvania, New York, Michigan, and Ohio; "you infrareders have developed tremendous technology, you haveput systems up in space, you've operated complex infrared scanning systems in airplanes,"give us QC engineers a simple device that can measure surface roughness, or a device to determine test material types." We haven't done it. We have built fragile infrared sensors that have been inoperative after a few days use. I think we have a black eye in that industry because of this.

If you look down on the bottom of the line on viewgraph one, the totals are 49 million dollars for today's infrared market and I think we could achieve 240 million dollars annually and probably a lot more from that in the next five years.

Before I discuss new product development let me first show a rough comparison of how infrared systems development is done for the government and how it is done for non-government applications. First of all, I was professionally trained at the University of Michigan where I went to graduate school and then worked on government contracts for thirteen years. The development of infrared equipment for government applications normally takes the route shown in viewgraph two. The process begins with some government agency establishing applications normally a requirement for the system. Then the government issues an RFQ and, in response to the RFQ the industry then prepares a proposal which they pay for. After contract award, a feasibility study is prepared for that system, funded by the government. After passing acceptance tests the system is then manufactured in limited quantities for field tests. If those are successful, then full production is initiated, all at government expense. If you happen to make a mistake or two which happens occasionally then you may overun your contract by 50% and all this is funded by the government.

However, when developing commercial products you've got a different ballgame altogether. Here, you have to carefully identify the problem first. Then you must do a market study. You're going to have to spend your money for these tasks whether you like it or not. A systems design is next followed by the fabrication of a bread board unit. The bread board unit is then tested; if it works reasonably well, an engineering prototype is built and tested. At this point, a careful manufacturing cost analysis is performed on the device and the market data is reviewed to measure the

economic benefit. If all these things are good, production and sales are initiated. The total costs experienced prior to production range from $100,000 to $1,000,000 depending on the device. This risk is completely assumed by the equipment manufacturer.

Most of you are very familiar with the government business but not very knowledgeable about the other. The major mistakes made by infrareders and other high technology people with commercial products is that they don't identify the problem and list the requirements correctly. They most often decide what the user needs without much communication with him. So the company builds a square infrared radiometer to fit a round hole. This is demonstrated, for example, by a great need for IR equipment in the NDT applications yet, for these markets we have radiometers that are too fragile and unreliable, and infrared framing equipment that is too costly and too difficult to operate. So obviously the games you have to play to achieve sales in a non-military non-government market are enormously different than when you're going after the government markets. And, I believe that we haven't been doing the job correctly, in the past.

Some case histories showing mistakes made in the past might prove helpful to you. One of the markets Sensors, Inc., first went after because it was an easy job to do, we thought, was tire detect sensing market. The U.S. government has imposed some regulations on the manufacture of tires such that they must meet a minimum safety standard. To do this they have to test the tires on a sample basis as they come off the production line. The

instrumentation for doing that could be quite simple but the understanding of the infrared characteristics of the tire is very meager. Inflated, pneumatic tires are mounted on an axle, pushed up against a very large wheel that rotates. The pressure used to push the tire against the wheel simulates actual load conditions in an automobile. For aircraft tires the wheel is spun up to achieve tire speeds of 400 mph and for passenger car tires the tests are conducted between 15 mph and 150 mph. Other infrared companies have attempted to penetrate this market with framing cameras or with off the shelf radiometers. After considerable testing by tire companies it was determined that framing cameras have limited value in the application. There is a serious problem of synchronizing the framing camera with its tv raster scan to the rotating tire. Here you find the western stagecoach wheel effect, where it looks like its rotating backwards, or too slow forward, producing multiple images, which are impossible to interprete easily. Also, aircraft tires spinning at 400 mph explode easily wiping out the expensive, fragile optics. Sensors, Inc., tackled this problem by first working together with engineers in the field that are experienced in tire Quality Control tests. After some careful study we determined that a simple, but rugged and reliable radiometer was the answer. So we designed a unit that could sense a hot or cold spot with $\Delta T \geq 1^{o}F$ and resolve a 1/2-inch diameter spot size. This instrument is mounted so that it observes the side wall while the tire is spinning. This tire motion gives an effective circumferential scan. A good tire has a uniform temperature around the circumferential scan. A defective

tire produces an anomalous mechanical flexing when the defective region makes contact with the drive wheel. This anomalous flexing produces a non-uniform temperature pattern around the tire. This produces a corresponding infrared signal from the sensor. These studies have shown that one degree F temperature difference will be sufficient to pick out most of the defects that occur in tires. The next major problem was to design the radiometer with sufficient ruggedness to survive in this environment. The sensor heads' top is made out of 1/4-inch rolled steel. The base is made out of cast ductile iron. The preamplifiers are suspended by thick piano wires. The mirror is made of epoxy, a technique we have developed that can withstand considerable shock. When a tire is spinning under test it will often explode under these stress conditions. If it is an aircraft tire and its spinning at 500 mph an explosion produces a chunk of rubber as big as your fist which flies off and hits the sensor head. This has happened a number of times with our units and they survive. The customer kind of chuckles when you show him your infrared sensors equipment. He's sure it won't survive. He believes this simply because other infrared sensors have not survived. So he believes infrared equipment is intrinsically too fragile. To overcome this attitude we built a number of these systems at our expense and took them to these fellows with the statement "try it, you'll like it." The first thing he does is run a defective tire until it explodes to check your system for ruggedness and, if it can handle that test, he is willing to believe that it may work. To date we have sold over 100 sensors for a total of about $300,000 in the last two years.

Every major tire company in the world is now a customer of ours. We expect the market to grow quickly.

Another application that we've looked at that we think is quite substantial is quality monitoring of welded steel tubes. Welded tube is made by taking a flat steel stock coiled up in a roll and run it through a hammer mill so that its bent up into a continuous cylindrical shape. At the seam a high electrical current is run through the pipe and the seam melts and fuses together to form what they call seamless tubing. There are some serious problems in this industry because in applications where the tubes are used to hold liquids at high pressure and high temperatures they find that small imperfections in the seam eventually burst, leading to a loss of the contained materials. We designed an infrared system that has two channels in it, one is a DC channel which measures the temperature of the seam and, the other channel is an AC radiometer designed to detect hot and cold spots. Both of them operate simultaneously in the sensor's head using the same optics. Since the pipe is made continously the sensor monitors the seam for defects. Hot spots or cold spots with a ΔT greater than some set in value will trigger an alarm. Also, a gradual seam temperature drift out of prescribed limits will trigger an alarm. These alarms are visual and audible and they are used to apply paint on the spot of the seam that is defective. This market is quite good. There is no other vendor currently selling radiometers here.

Finally, in conclusion the last viewgraph lists some of the things that you and I have to do to take this technology that has

been developed over the past 20 years at government expense. I think a careful survey of existing applications is needed. Somebody has to collect that information, put it together, for current and future vendors. This application compilation should contain a descrption of basic principle involved and the engineering formulas used for analysis and test purposes. Also include any peculiar design problems. We need such a document to help educate our customers.

I think we must also study new applications of infrared technology. Somebody has to look at these new applications, do a quick analysis to find out if an infrared approach is technically feasible or not. If possible, this study should be followed by a cost benefit analysis. You'll find that if the numbers warrant it, the companies will spend their money to develop and sell the product. Its getting over the first hurdle that infrared companies usually fall short.

I believe that we also need a better arrangement on patents issued under government contracts. Right now if you've got a good idea, and you go to the government for contractual support you pretty much have to concede ownership of that device patent to the government agency. What this does is water down the companies enthusiasm for spending money at a later date toward using that same idea for non-government applications. I can say from my own practices as President of Sensors that if I authorize a half of a million dollars for development of a system the first thing I require is a strong patent position to insure that I'm not driven out of the market by a larger company. I want to be

sure to obtain as much of the market as I can before competition becomes a serious factor. This is always one of the first questions asked about a new invention in industry. Today I think the government's position on patents tends to let good applications slip through the cracks.

That's all I have to say. Thank you very much, gentlemen.

Viewgraph No. 1

Non-Government IR Markets

Market		$/Year Now	$/Year Future
1.	Spectrometers	30 M	30 M
2.	Tem. Meas. Radiometers	10 M	15 M
3.	Auto Emission Analyser	2 M	25 M
4.	Indust. Gas Monitors	5 M	20 M
5.	Tire Defect Sensing	1 M	5 M
6.	Intrusion Alarm	2 M	20 M
7.	Fire Suppression	0	5 M
8.	Insect Pest Control	0	50 M
9.	Emission Spectrograph	0	20 M
10.	Surface Roughness	0	50 M
	TOTALS	49 M	240 M

Viewgraph No. 2

IR Systems Development and Manufacturing

Financial Support	
V	Identify Problem*
V	Market Analysis*
V	System Design
V	Breadboard Fabrication
V	Prototype Design
V	Prototype Fabrication
V	Prototype Test
V	Cost Analysis*
V	Manufacturing Prototype
V	Production
V	Sales

Financial Support	
G	Establish Requirement
G	Issue RFQ
V	Prepare Proposal
G	Feasibility Study
G	Prototype Design
G	Prototype Fabrication
G	Prototype Test
G	Limited Manufacture
G	Production

V - Vendor
G - Government
* - Likely source of errors

Viewgraph No. 3

What is Need to Open
Non-Government Markets

1. IR Applications HANDBOOK for Engineers
2. Study of Potential New Applications
3. Careful Market Studies
4. A Better Arrangement on Patents Issued Under Government Contracts

COMMERCIAL AIRBORNE SCANNERS

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The airborne infrared scanner had its origin with the military who developed it for passive night viewing. While the military developed the infrared airborne scanner, optical mechanical scanners have been around for some time as they were the basis of early television systems prior to the development of the electron beam scanning image tubes. The principal of operation of a scanner is shown in fig. 1.

The field of view of an infrared telescope (radiometer) is reflected from a rotating mirror such that it scans the ground in lines perpendicular to the flight path of the aircraft. The scan rate is adjusted so that succeeding scan lines are adjacent or overlapping as the aircraft moves forward. Thus, the rotating mirror provides the scanning motion normal to the flight path while the aircraft motion advances the scan pattern. The output signal from the detector is amplified and used to intensity-modulate a light source. The result is a graphic image of the scene radiance. The military development of scanners was inspired by their desire to be able to see at nighttime. Their development concentrated on making high resolution, high contrast imagery. They were not interested in quantitative measurement of temperature. Since they developed the scanner, they classified them. As a result, the civilian community did not have access to scanners.

Largely through efforts of the Univ. of Michigan who were using obseleted, but still classified, military scanners and Bendix who built one without a DOD contract, DOD relaxed the classification of scanners. They devised a figure of merit based on operation parameters.

$$\mathrm{FOM} = \frac{\sqrt{V/h\theta}}{\beta^2 \ \Delta T} \qquad (1)$$

where

	V/h	is the aircraft velocity to height ratio
	θ	is the angular swath width
	β	is the instantaneous field of view
	ΔT	is the temperature difference which gives an RMS S/N = 1.

If the scanner FOM is less than 4.5×10^5, it is unclassified. One can view the figure of merit as a measure of how much information is collected by the system. It can be shown that the FOM is also related to design parameters. The well known performance equation for scanners can be written as

$$\mathrm{FOM} = \frac{V/h\theta}{\beta^2 \ \Delta T} = \frac{\tau \ \pi D D^* \frac{\Delta L}{\Delta T} \sqrt{2p\gamma}}{4 \ n_f F} \qquad (2)$$

where	τ	=	the optical transmission
	D	=	collector diameter
	D*	=	detector detectivity (a figure of merit)
	$\frac{\Delta L}{\Delta T}$	=	the change in radiance within the optical passband for a temperature change of 1°K
	P	=	number of detector elements
	γ	=	scan duty cycle (ratio of active scan to total scan)

The left hand side of equation (2) can be interpreted to read that a scanner is classified if one wants to operate in a high V/h aircraft, have high resolution (small β), or have a high temperature sensitivity. To achieve this, the right hand side of the equation shows that one must have a large diameter optical system, a high scan efficiency, and/or a large number of detector elements.

The civilian community generally does not use high performance aircraft or need high spatial resolution. All factors considered, they want an inexpensive, simple instrument which is capable of making quantitative or semiquantitative temperature measurements. Thus one finds that the civilian market is based on requirements considerably different from the military. To obtain quantitative data, the civilian scanners incorporate dc, wide bandwidth electronics to maintain video fidelity, they use calibration sources so they can sense apparent radiation temperature, and they employ tape recording of the data. Tape recording provides wide dynamic range and permits the data to be processed in a number of ways. The taped data can be processed to bring out fine temperature structure on one playback and to show overall gross details on another. For example, the data can be played back to show fine thermal structure in low temperature water while on a second playback the detailed structure of warm terrain. On still another playback one can perform thermal slicing or contouring.

An example of a commercial scanner is the Bendix thermal mapper LN-3. This scanner, shown in Fig. 2 with some optional accessories, has a 3" collecting aperature. The 70 mm film recorder is an integral part of the basic scanner shown in the center of the picture. Accessories shown in the figure include an interchangeable detector, blackbody calibration sources, and roll stabilization. Table 1 lists comercially available thermal scanners and some of their operational and design parameters. Typical of the quality of imagery that one can get with an unclassified scanner is illustrated in fig. 3. This daytime imagery of Nebraska farmland was taken from an altitude of 3000 ft. The grey scale at the edge is the tone of a blackbody of 15°C.

Returning to the DOD security classification guideline, it may be interesting to note what type of scanner is unclassified and how well will it perform. Assume a scanner operating in the 8 - 13μm region with the following design parameters:

τ	=	50%
D	=	7.5 cm (3 inches)
D*	=	3×10^{10} cm/watt
p	=	1

γ = .33

F = 3

The resulting FOM = 7.5×10^5. This would be unclassified by a factor of two as DOD has recently relaxed the FOM to 1.5×10^6.

As for what performance one can get with an unclassified scanner, assume:

V = 150 mph

h = 1/5 mile

θ = 90°

β = 1.5 m radian

Then ΔT (RMS) = 0.12°C. This would correspond to an NEΔT (peak signal to RMS noise) of about .14°C. Thus one has more than adequate temperature resolution (20 levels per °C).

One area of scanner development that the civilian sector has pioneered is the multispectral scanner. This development was begun by University of Michigan researchers back in 1964. A schematic of a multispectral scanner is shown in fig. 4. While most scanners use a detector or a field stop imaged on the detector to define the field of view, the entrance slit of a multichannel spectrometer is used in this sensor. In such a system, each detector of the spectrometer observes the same resolution element of the scene but in a different wavelength region. The output signal from each detector element is a video signal corresponding to the scene brightness in the particular wavelength region of operation. This video signal can be used to generate an image of the scene in the wavelength region as defined by the position of the detector in the spectrometer. The output signals from multiple detectors can be combined to determine the spectral distribution of the radiation from each scene point. This spectral information then can be used to enhance or suppress the detection of objects or materials in a scene. If the detection can be repeated with confidence (high reliability with acceptable misclassification), one has a recognition or automatic classification sensor.

It should be noted that the multispectral scanner avoids many of the registration problems inherent in a multi-sensor system, i.e., one which used multiple sensors - photography, infrared, and radar. The spectral information from the various channels of the multispectral scanner is collected with complete registration in both time and space domain. The schematic of a multispectral scanning system is shown in fig. 5. The signal from each detector is recorded on tape. The tape is brought back into the laboratory and processed to obtain the spectra of targets and backgrounds. At maximum V/h, the scanner collects 70,000 spectra/sec. With this quantity of data one gets statistical information about the nature of targets and backgrounds. This information can be used to train a computer to perform automatic recognition or classification of features based on their spectral properties.

The most sophisticated multispectral scanner system built to date is the 24 channel system built by Bendix for NASA/Houston. To cover the spectral region from .32 to 13.5 μm, this nine inch aperture scanner uses PM, Si, Ge, InSb and Hg:Ge detectors. The airborne scanner system including the video digital recording system is shown in fig. 6. A close-up view of the scanner is shown in fig. 7. The large structure is referred to as the calibration arch and houses two aperture filling blackbodies and an aperture filling integrating sphere.

The ground station shown in fig. 8 is used to view, edit and process the data. The objective of this station is to determine means by which terrain features can be classified automatically using multispectral data. Examples of the type of task scientist are trying to accomplish are shown in figs. 9 and 10. Fig. 9 is a Bendix generated classification image of agricultural fields. The ground truth shown on one of the images was provided by scientists from USDA/Weslaco. Fig. 10 shows a computer generated soil map made by Purdue scientists. In this map,distinction is made between light, medium, and dark soils by using different printout symbols.

Table II lists airborne multispectral scanners and some of their characteristics. Figs. 11 and 12 show the Bendix M^2S scanner and control electronics. The specifications for this eleven band scanner are given in Table II. Imagery from four bands of the M^2S scanner are shown in Fig. 13.

The preceeding discussion has emphasized commercially available airborne scanners. It should be noted that meteorologist have used thermal scanners in the space program and have used multispectral scanners for cloud mapping and heat budget studies. More recently NASA has orbited a four channel multispectral scanner on ERTS and will orbit a 13 channel scanner on SKYLAB.

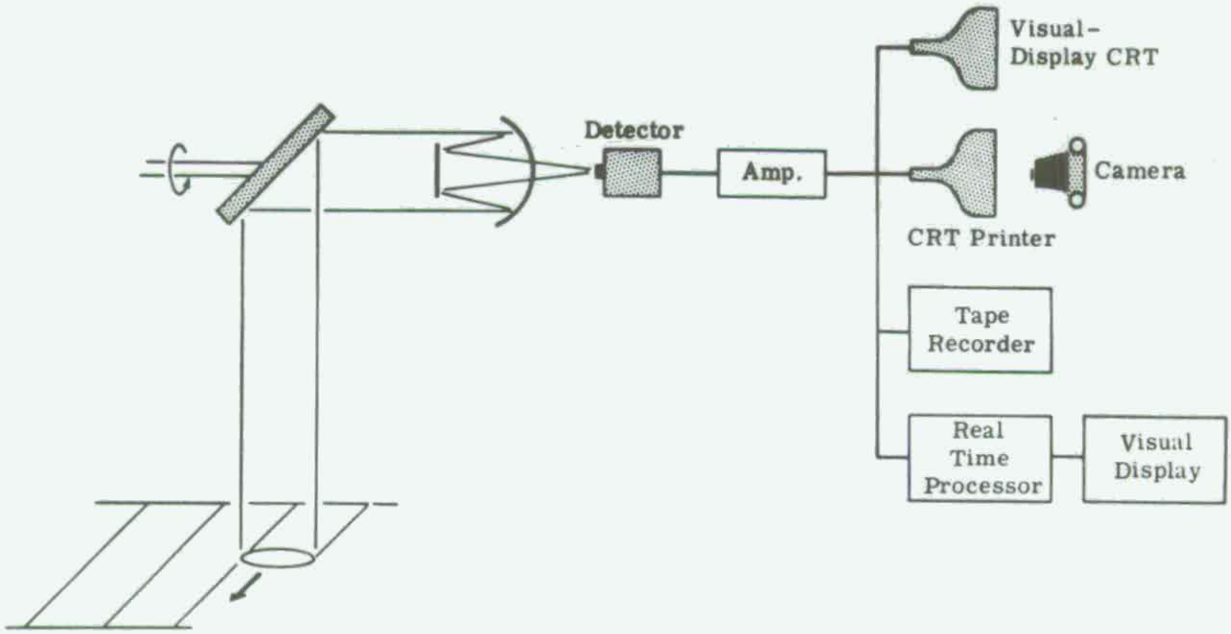


Fig. 1 Schematic of an Airborne Line Scanner

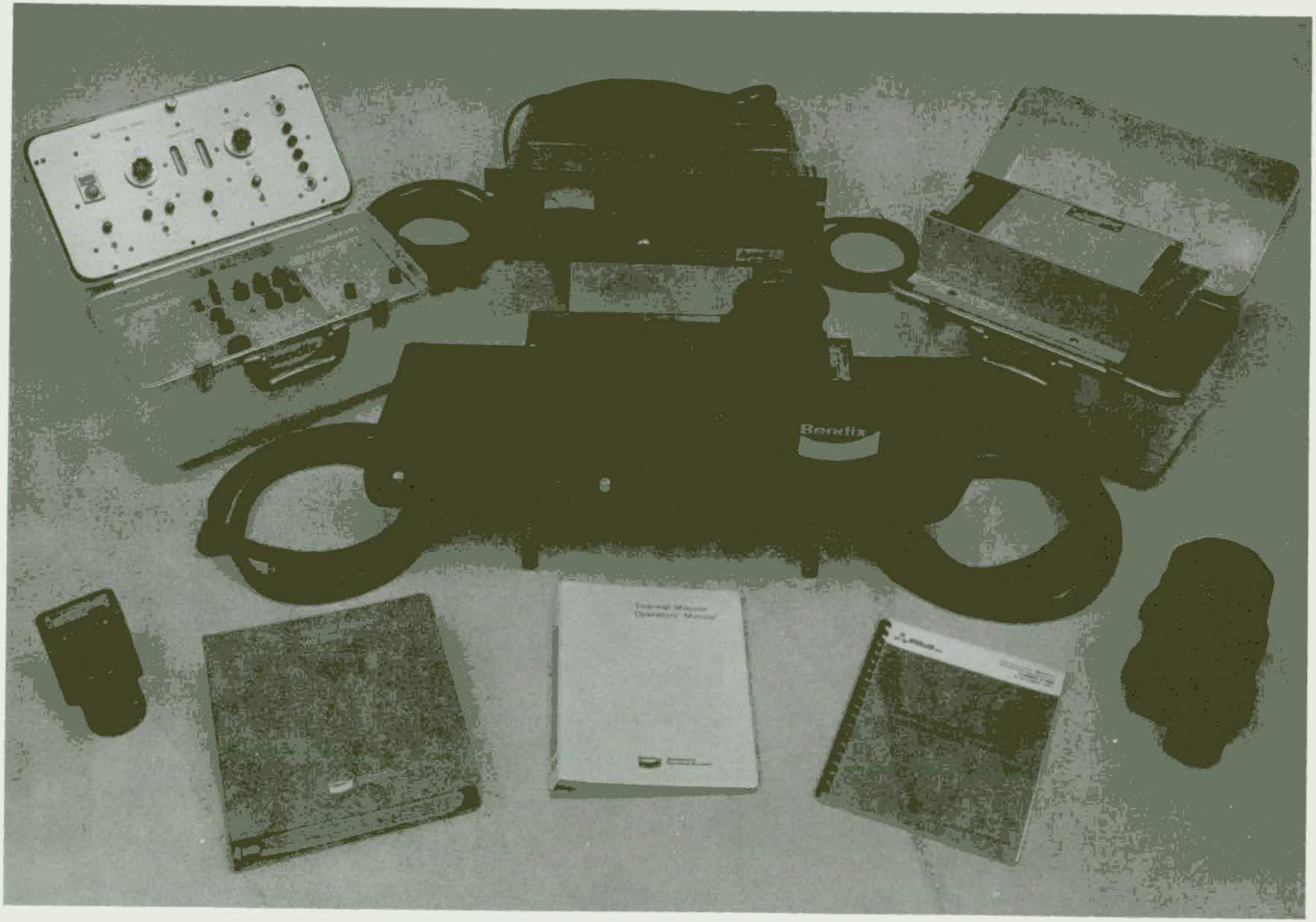


Fig. 2 Bendix LN-3 Thermal Mapper with Accessories

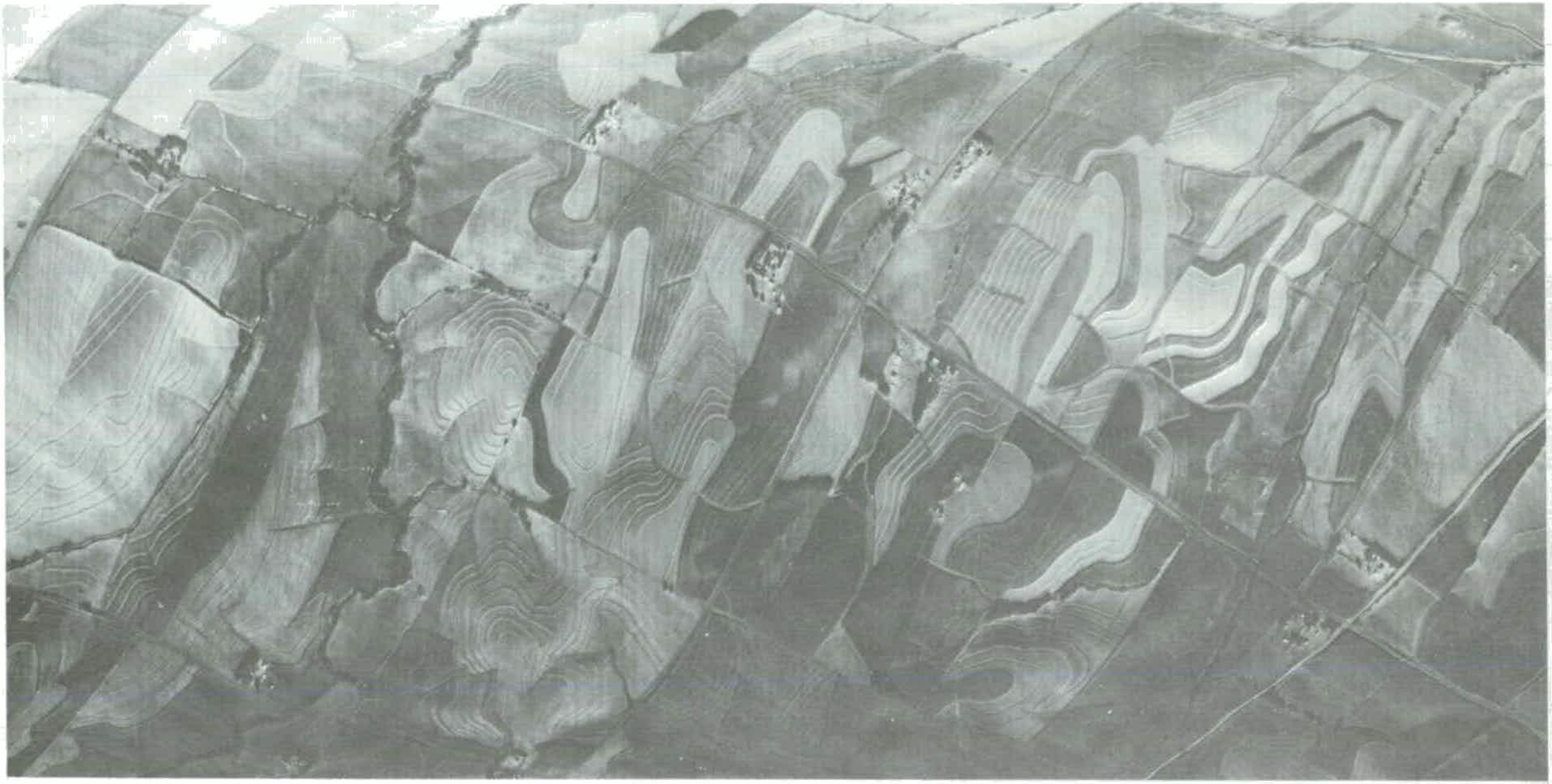


Fig. 3 Thermal Image of Nebraska Farmland with Blackbody Calibration Strip - 1130, 7 October 1969 - 3000 ft

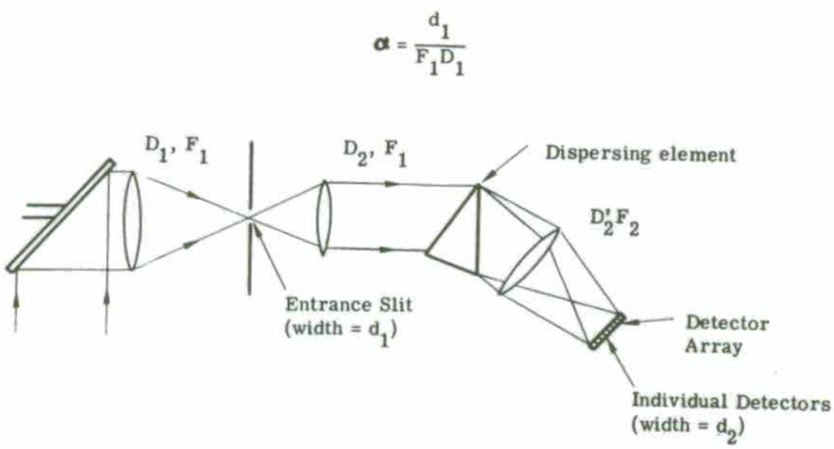


Fig. 4 Optical Schematic of a Dispersive Multispectral Scanner

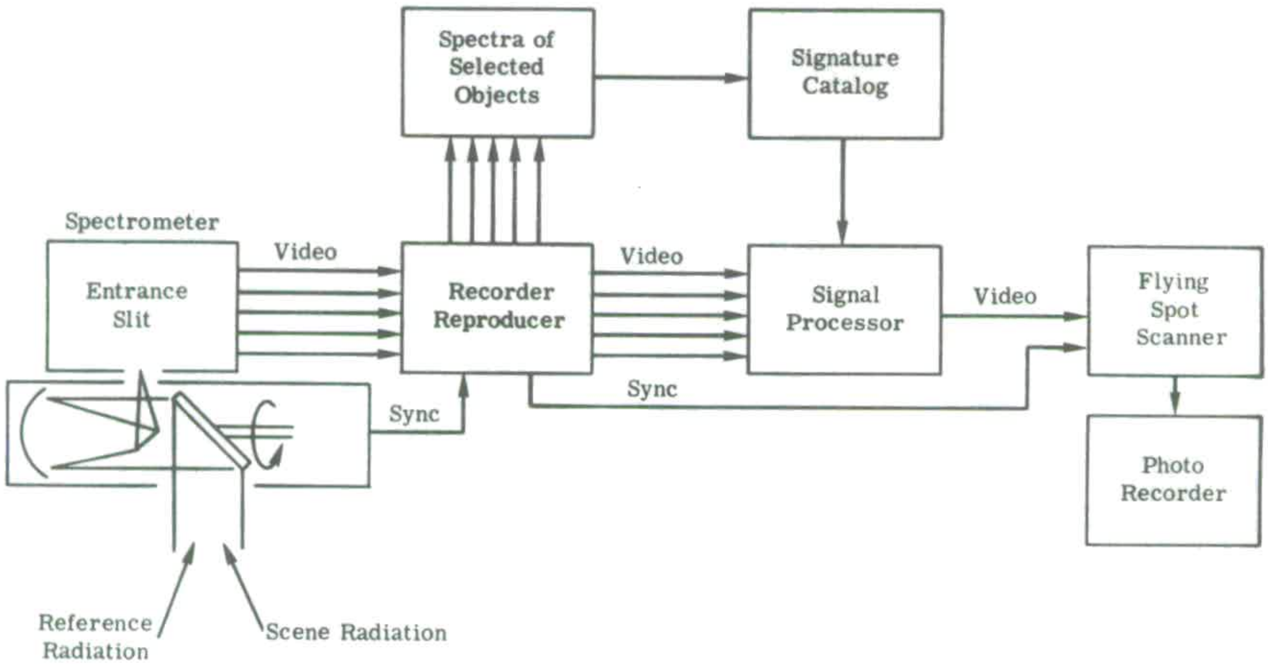


Fig. 5 Schematic of a Research Multispectral Scanner System

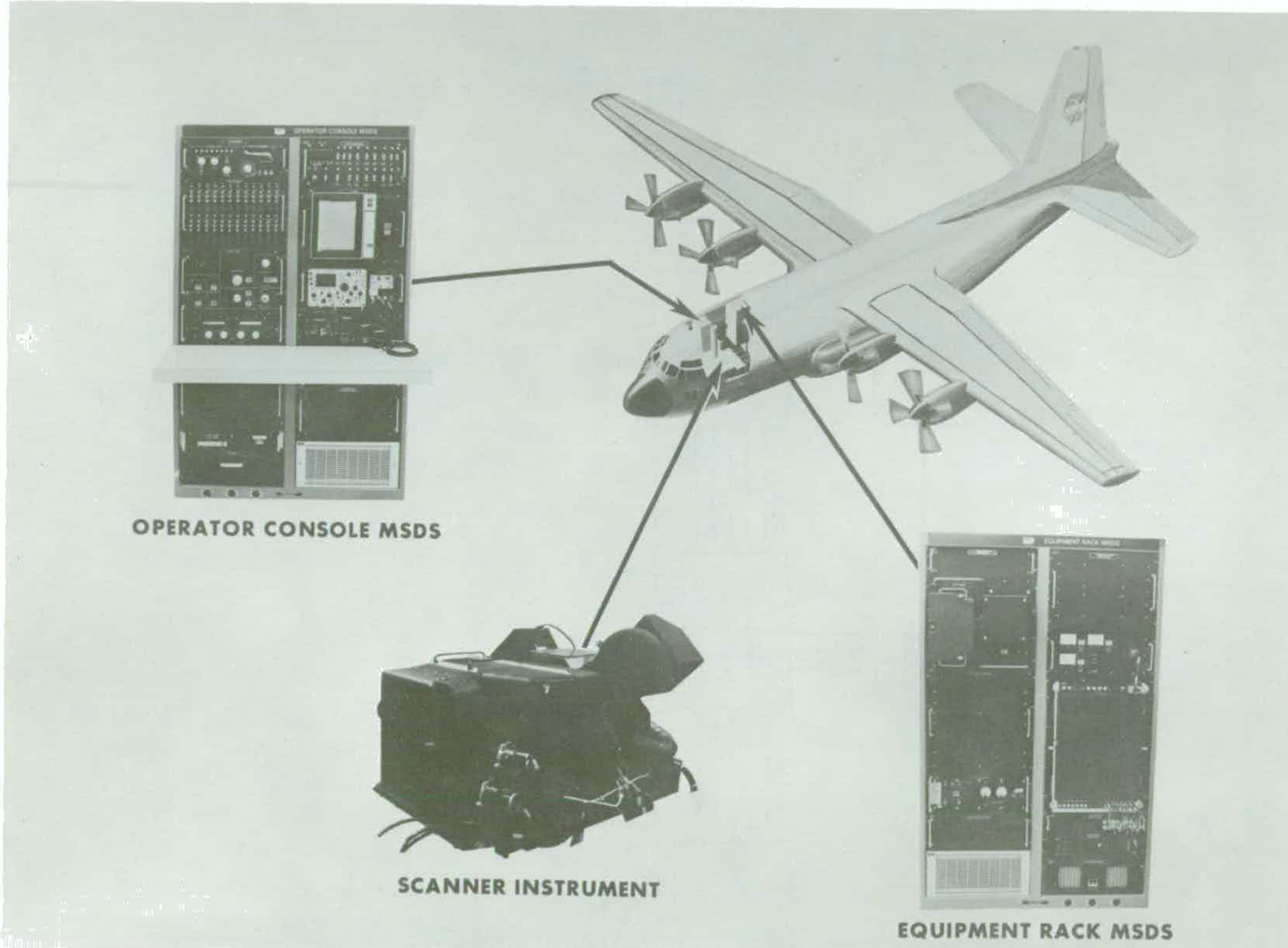


Fig. 6 Airborne Elements of NASA's 24 Channel Multispectral Data System (MSDS)

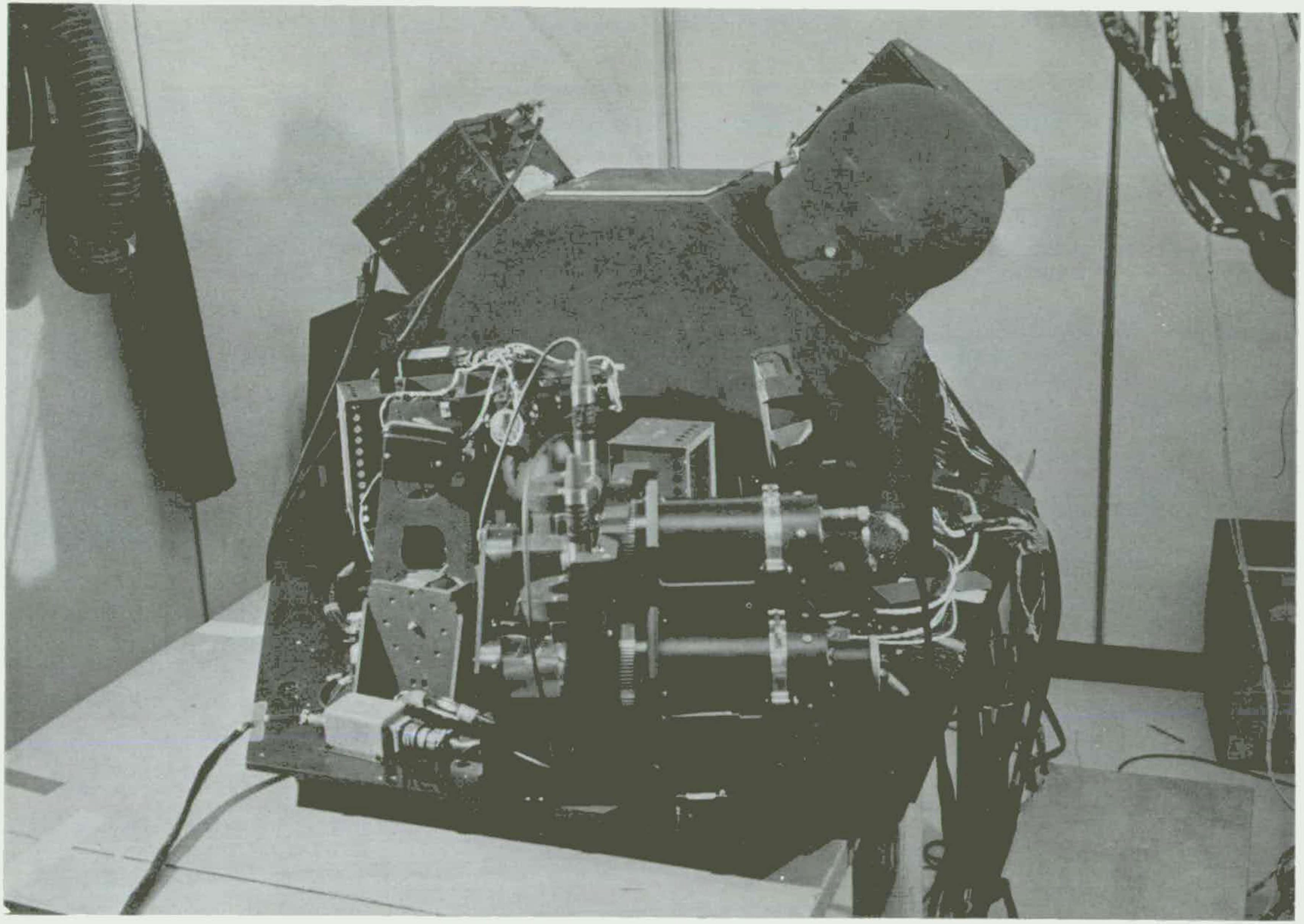


Fig. 7 View of the 24 Channel Scanner

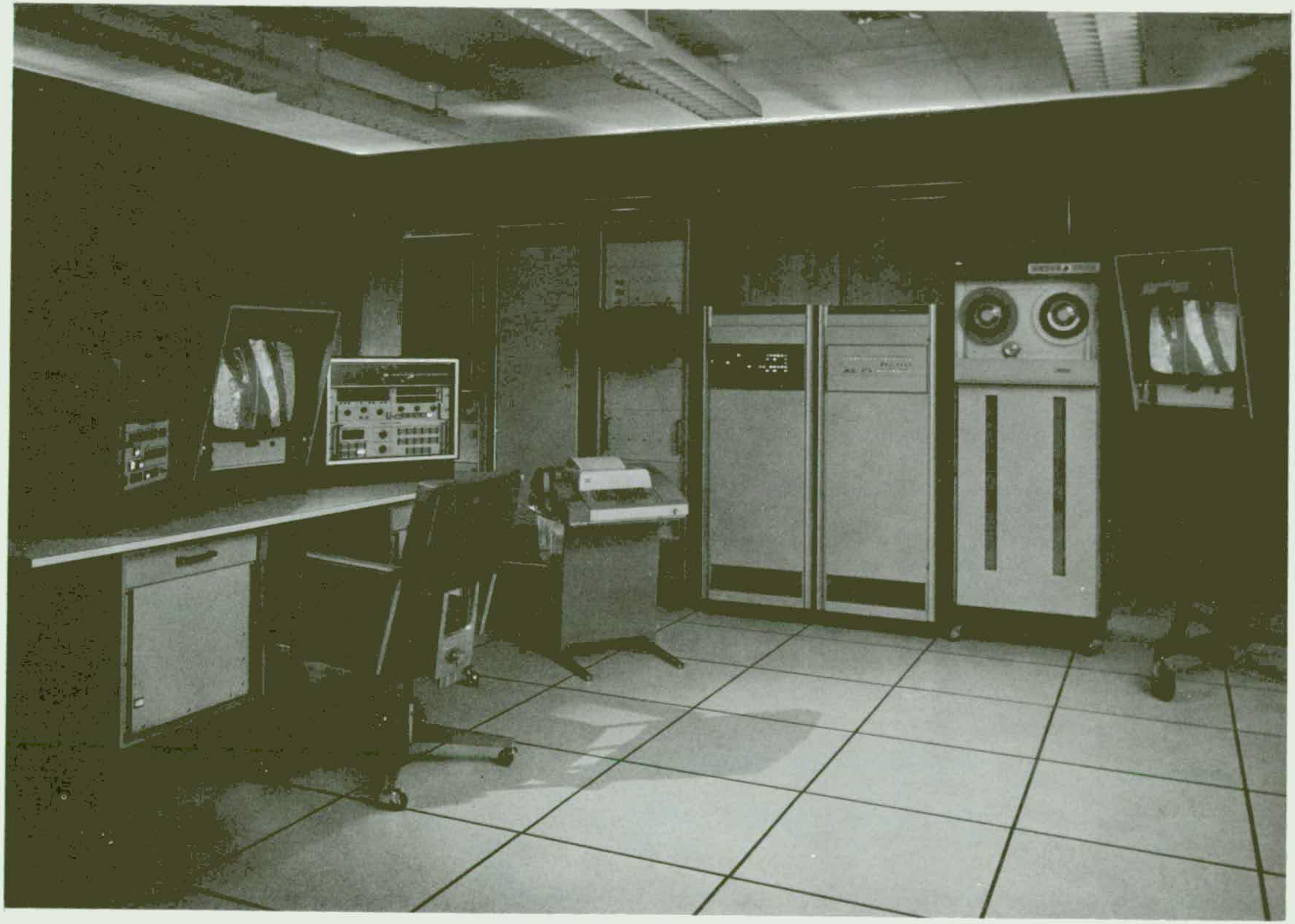
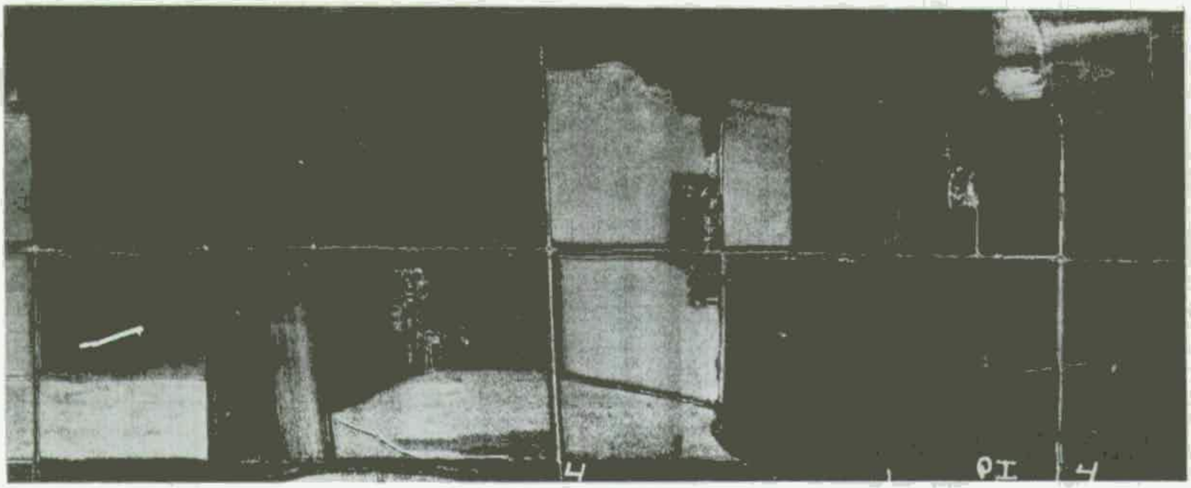
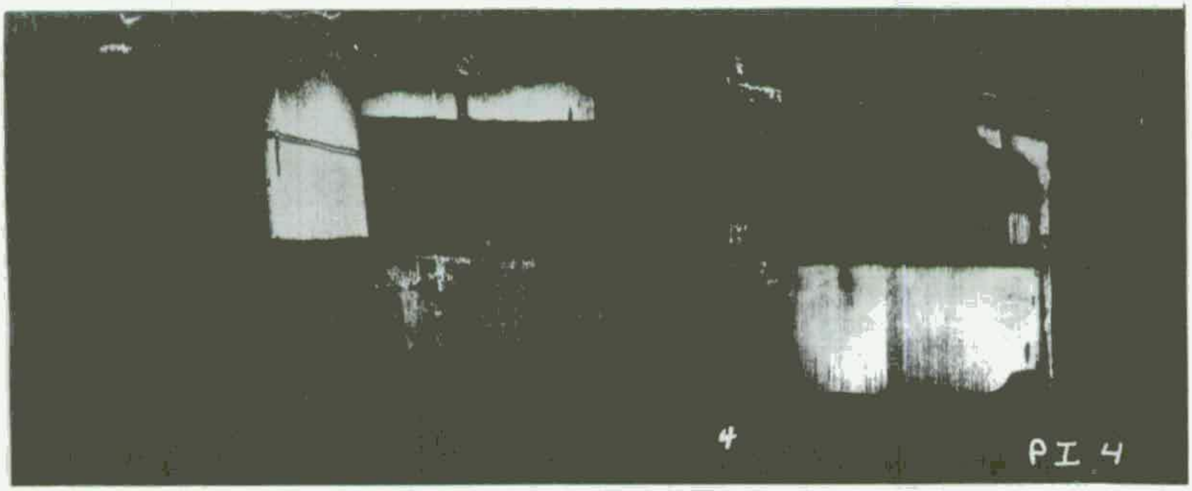


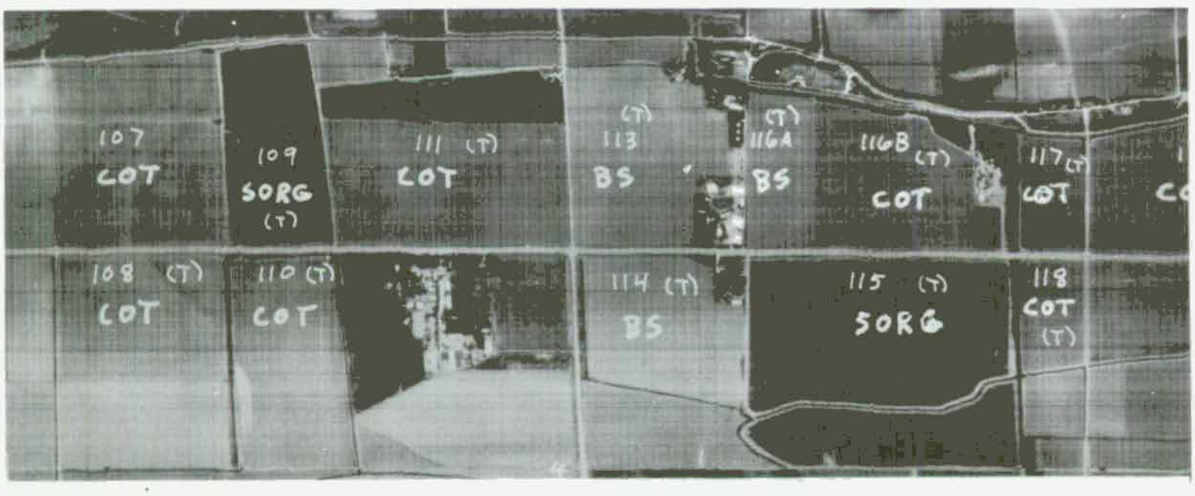
Fig. 8 Data Analysis Subsystem of MSDS



BARE SOIL



SORGHUM



GROUND TRUTH

Fig. 9 Classification of Soil and Sorghum Based on Spectral Signature

Fig. 10 Computer Recognition of Soil (Purdue University)

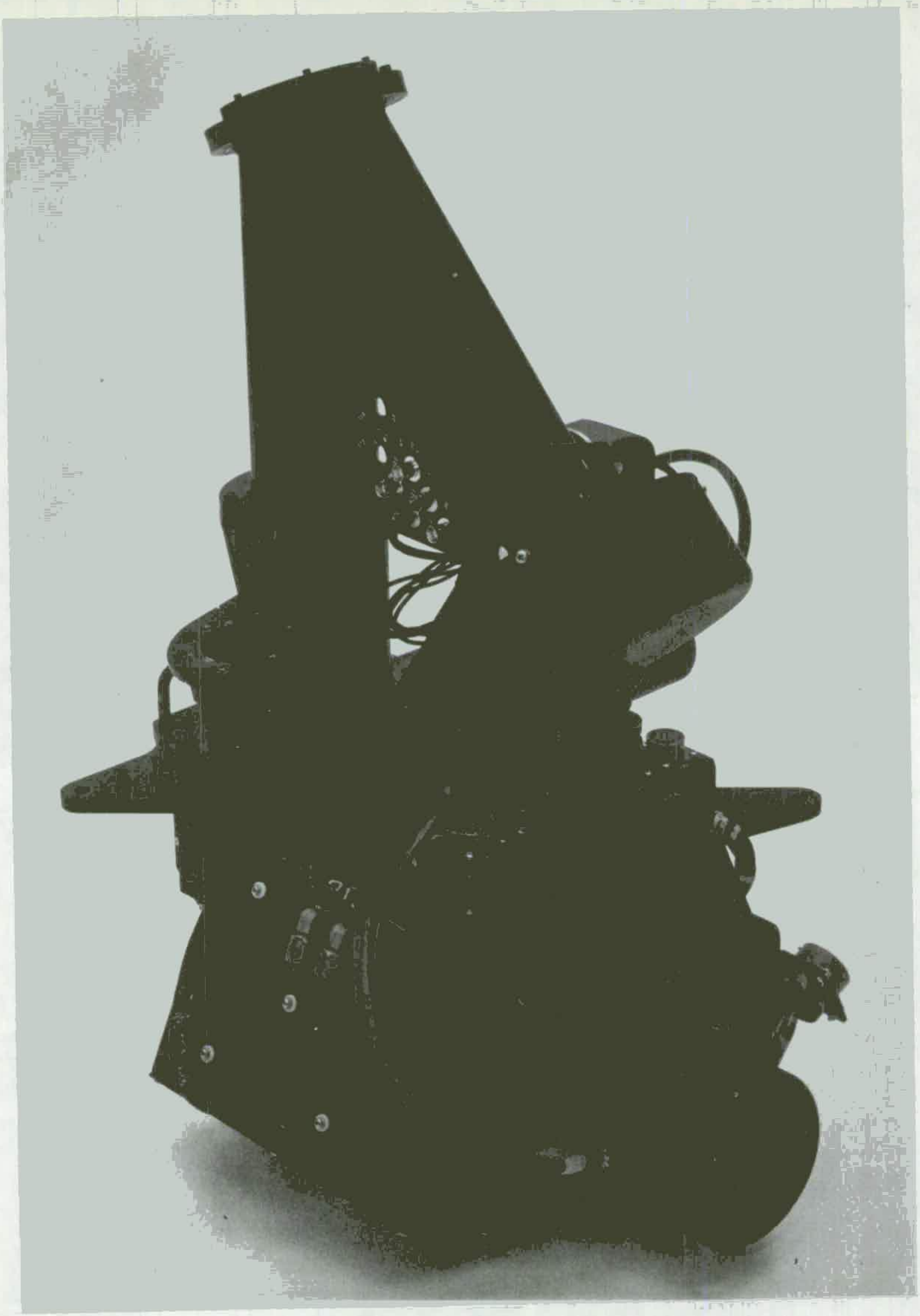


Fig. 11 Bendix M^2S - Modular Multispectral Scanner

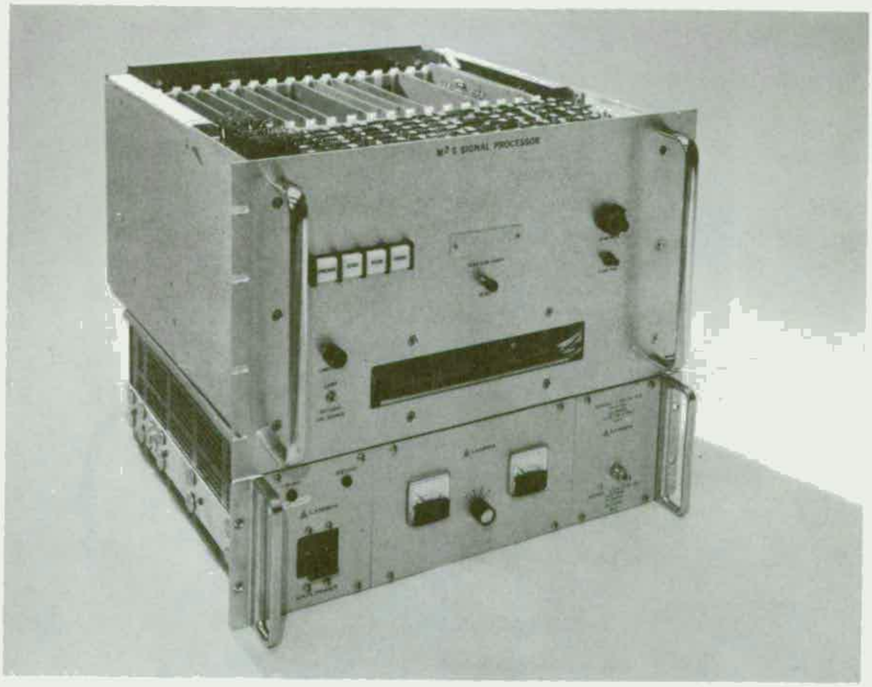
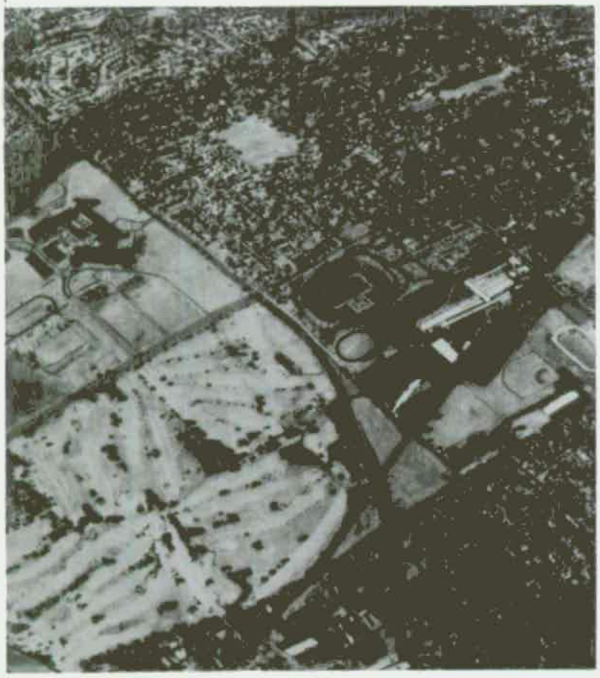


Fig. 12 M^2S Electronics

M^2S IMAGERY

BAND 1 380 - 440 nm

BAND 4 540 - 580 nm



BAND 8 700 - 740 nm

BAND 11 8-13 Microns

Fig. 13 Sizzle Band M^2S Imagery

TABLE I COMMERCIALLY AVAILABLE INFRARED SCANNERS

Mfr Model	Method of Scanning	Lines/Sec Rate of Scan RPM	Size of Resolution Element mRad	Swath Width Degrees	Type of Collecting Optics	Focal Length	f/no	Effective Collector Area	V/H Max
Texas Inst[1] RS-310	4 Sided Prism	200	1.5	90°	Reflective	15 cm	2.1	40.5 cm^2	0.3
TRW Hawker[2] Siddeley			1.5	120°					0.75
Daedalus[1] DEI-100	Double Faced 45° Mirror	120	2.5	120°	Newtonian	15 cm	1.2	45 cm^2	0.3
Daedalus[2] DS-1200	45° Mirror	80	2.5	77°	Newtonian	15 cm	1.2	40.7 cm^2	0.2
HRB Singer[1] Reconofax IV	45° Mirror	185	2 or 3	120° or 140°	Newtonian	15 cm	1.8	47.6 cm^2	0.37 to 0.56
Reconofax VI[1]	Double Faced 45° Mirror	370	2 or 3	120° or 140°	Newtonian	15 cm	1.8	21. cm^2	0.75 to 1.1
Reconofax XI[1]	Double Faced 45° Mirror	133	1.5	120°		25 cm	2	48 cm^2	0.20
HRB Singer[2] Reconofax XIIIA Model 13-21	4-Sided Prism	800	1 and 2 mr. (in same dewar)	120°	Reflective	10 cm	1.5	35 cm^2	1.6 rad./sec
Bendix T/M[1] LN-3	45° Mirror	100	2.5	120°	Dall-Kirkham	30 cm	4	45.5 cm^2	0.25

1 Data obtained from Infrared Information and Analysis Center, University of Michigan
2 Data Obtained from Mgf. Literature

TABLE I COMMERCIALLY AVAILABLE INFRARED SCANNERS (Continued)

Spectral Bands of Each Channel μm	Type of Detector	NEΔT °K	Method of Recording	Weight Lbs.	Power
	S-13 PM Silicon		Film	96.5	dc: 28 V, 9-amp
	In:Sb	0.48	tape recording optional		ac: 110 V, 400 Hz, 8-amp
	Ge:Hg Hg:Cd:Te	0.20			
7.5 - 14	Hg:Cd:Te	0.5	Film	25	dc: 28 V, 6-amp
.35 - 1.0 1.0 - 5.5 8.0 - 14	PM In:Sb Pb:Sn:Te	0.3 0.2	tape recording film optional	65	dc: 28 V, 5-amp
.35 - 1.0 1.0 - 5.5 8.0 - 14	PM In:Sb Pb:Sn:Te	0.3 0.2	tape recording film optional	85	dc: 28 V, 5-amp
	Ge:Hg In:Sb	0.3	Film	55 Scanner plus 20 for closed cycle cryostat	ac: 3-phase, 115V, 400 Hz 4-amp surge, 1.5-amp steady
		0.5			ac: 3-phase, 115V, 400 Hz, 5-amp surge, 3-amp steady (cooler)
	Ge:Hg In:Sb	0.5 0.7		55 Scanner plus 20 for closed cycle cryostat	Same as Reconofax IV
 8 - 14	In:Sb Ge:Hg	0.32 0.2	Film	109 lbs	dc: 28 V, 8-amp
8 - 14	Hg:Cd:Te	0.3 at 1 mr. 0.2 at 2 mr.	Film	135, including cooler and stabilized mount	28 VDC @ 4.3 Amps. 115 VAC, 400 Hz, 3-Phase, 400 Watts
0.38 - 0.6 0.2 - 0.6 1.0 - 5.5 8.0 - 14.0	S-11 PM S-13 PM In:Sb Hg:Cd:Te	 0.3 0.2	Film tape recorder optional	55	dc: 28 V, 5-amp

TABLE II AIRBORNE MULTISPECTRAL SCANNERS

Manufacturer Model	University of Michigan Experimental Multispectral Scanner M-7	Texas Instruments RS-14
V/H Max.	0.12 or 0.20	0.2
Method of Scanning	Single 45° Mirror	4-Sided Mirror
Scan Lines/Second	60 or 100	
Swath Width Degrees	90	80
Resolution 1FOV m rad.	2 Max.	1 or 3
Type of Collecting Optics	Dall-Kirkham Plus Concentric Lens System	Dall-Kirkham
Focal Length and f/	Dall-Kirkham-508mm f/4.0 Lens System-76mm f/1.0	254mm f/3.7
Diameter of Aperture	Dall-Kirkham-127mm Lens System-76mm	
Effective Aperture Area	Dall-Kirkham-8107mm^2 Lens System-4560mm^2	3740 mm^2
Roll Compensation	Signal ± 10°	Signal ± 8°
Calibration in Flight	Blackbodies, Q-I Lamps, Sky	Blackbodies, Q-1 Lamp
Method of Recording	Magnetic Tape	CRT with Film
Method of Spectral Separation	Beam Divider, Dichroic Beam Splitter, Filters and Prism	Dichroic
Total Weight (less recorder)	225 Kg (500 lbs)	120 Kg (264 lbs)
Power	882 W 28 VDC 1250 W 400 Hz 115 V 594 W 60 Hz 115 V	154 W 28 VDC 876 VA 115 VAC
Source of Specification	University of Michigan	IRIA, Mfg. Lit.
Spectral Bands	0.32 - 0.38μm 0.40 - 0.44 0.44 - 0.46 0.46 - 0.48 0.48 - 0.50 0.50 - 0.52 0.52 - 0.55 0.55 - 0.58 0.58 - 0.62 0.62 - 0.66 0.66 - 0.72 0.72 - 0.82 0.82 - 0.96 1.0 - 1.4 1.5 - 1.8 2.0 - 2.6 8.0 -13.5 Any 12 bands can be recorded at one time.	0.3 - 0.55μm 0.7 - 0.9 1.0 - 1.5 1.5 - 1.8 2.0 - 2.5 3.0 - 5.5 8.0 - 14 Only two of the bands can be used at one time.

Bendix Aerospace Systems Division Modular Multi-spectral Scanner (M^2S)	Bendix Corp. Aerospace Systems Division Multi-spectral Data System	Daedalus Enterprises Daedalus Spectrometer Module DS-1050	Actron Ind., Inc. HMS-564X
0.25	0.18	0.2	0.1
Single 45° Mirror	Single 45° Mirror	Single 45° Mirror	Conical
100	9.2-90	80	50
100	80	77	51.3°
2.5	2.0	2.5	2
Dall-Kirkham	Dall-Kirkham	Paraboloidal Newtonian	Cassegrain
400mm f/4	1142mm f/5.0	152mm f/2	
100mm	228mm	127mm	150mm
6500mm^2	38100 mm^2	4560 mm^2	
Signal ± 10°	Signal ± 8°	Signal ± 10°	No, Stabilized Mount Optional
Blackbodies, Q-I Lamp Sunlight	Blackbody, Q-H Lamp, Sky Ref.	Q-H Lamp	Lamp
Magnetic Tape	14 Track Digital Magnetic Tape	7 Track Magnetic Tape	Magnetic Tape
Diffraction Grating/Dichroic	Diffraction Grating	Prism	Prism/Beam Splitter
118 Kg (261 lbs)	1273 Kg (2800 lbs)	54.3 Kg (120 lbs)	79 Kg (175 lbs)
7 AMP 115 V 400 Hz 15 AMP 28 VDC	1155 W 28 VDC 10.2 KVA 115 V	132 W 28 VDC	280 w 28 VDC
Mfg. Lit.	IRIA, Mfg.	Mfg. Lit.	Mfg.
0.38 - 0.44µm 0.44 - 0.49 0.49 - 0.54 0.54 - 0.58 0.58 - 0.62 0.62 - 0.66 0.66 - 0.70 0.70 - 0.74 0.76 - 0.86 0.97 - 1.05 8.0 - 12.0	0.34 - 0.40µm 0.40 - 0.44 0.46 - 0.50 0.53 - 0.57 0.57 - 0.63 0.64 - 0.68 0.71 - 0.75 0.77 - 0.81 0.82 - 0.87 0.97 - 1.06 1.06 - 1.095 1.13 - 1.17 1.18 - 1.3 1.52 - 1.73 2.1 - 2.4 3.54 - 4.0 4.5 - 4.75 6.0 - 7.0 8.3 - 8.8 8.8 - 9.3 9.3 - 9.8 10.1 - 11.0 11.0 - 12.0 12.0 - 13.0	0.38 - 0.42µm 0.42 - 0.45 0.45 - 0.50 0.50 - 0.55 0.55 - 0.60 0.60 - 0.65 0.65 - 0.70 0.70 - 0.80 0.80 - 0.90 0.90 - 1.10	0.5 - 0.6µm 0.6 - 0.7 0.7 - 0.8 0.8 - 1.1 10.4 - 12.6

HOW CRITICAL ARE QUANTITATIVE IR MEASUREMENTS TO THE CONSUMER?

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Introduction

I am not in a position to give you statistics. In fact if any statistics exist at all, for the civilian application of infrared technology, they haven't made themselves evident. We are not at the statistics-producing stage yet. At NBS, furthermore we are really just beginning in the business of technology forecasting. We're undoubtedly making many mistakes along the way. But our experience does not leave us totally ill-equipped to predict some of the problems you may be facing very soon. We can say something about the ways that some problems can be avoided. Rapid growth in IR measurement can come without all of the pain that accompanies progress in other areas, where it cannot so easily be predicted.

Why Is NBS Forecasting?

Why are we suddenly interested in technology forecasting? Our interest in this business has recently been stimulated by new questions that Congress and the Executive Branch have been asking us, about what we are doing and why. This interrogation has caused us a bit of soul searching, which is valuable, of course. In the past, as you know, we have prided ourselves in working at the state-of-the-art in many measurement areas. Such work is typically designed to provide the answer to tomorrow's problems rather than today's. This is largely as it should be in the best of all possible worlds. If routine measurements must be made at the state-of-the-art, that is, if requirements for routine measurements have not been anticipated, great difficulty arises. If, for example, you had to take fifteen readings and average them, to tell time with the precision necessary for routine work, we'd all have a lot less clear idea exactly what time it is. Telling time would be horribly expensive and disagreements would be a severe problem.

But that's exactly "where it's at" with the measurement of optical radiation in other spectral regions, that is in the visible and near UV, (it is a lot later than many realize!). The results of the best, most

painstaking, work are barely good enough for many purposes. More broadly, many present disagreements are intolerable; and the care required for this inadequate performance, moreover, makes it exceedingly expensive. In brief, in these other spectral regions we are paying too much for results that aren't good enough. Virtually everyone who finds himself for the first time having to treat these measurements really seriously finds himself very unhappy about paying so much for so little.

This situation says, therefore, that in the past we haven't been looking far enough ahead in providing for measurement capability. We have let our present needs catch up and even surpass both our present capability and its dissemination. Moreover, the present situation is not only costly in terms of having to make measurements inefficiently. The resulting disagreements are also costing our American industry very sorely.

One example is light emitting diodes (LED's). A recent intercomparison among LED manufacturers showed a spread among measurements of 44%. Clearly the consumer of this and many other products can resolve such disagreements only by the devotion of considerable, continuing resources to elaborate quality control. Much of this should be in principle unnecessary. It is increasing unnecessarily the cost of American products containing these and many other devices.

Two Choices For Industry

As infrared comes out from behind the classification curtain into an extraordinarily promising future, one can predict that one of two courses will be followed.

On the one hand, if we do not act, then IR measurement systems, whose performance in the past has been held within tolerable limits largely by the restricted nature of this community, will find themselves in much greater trouble in the future. The variety of measurements will be far greater, and they will be made by many more people.

On the other hand, if we plan intelligently, anticipating some problems before they become severe and facing others squarely when they do appear, then concerted action can avoid some problems and reduce the severity of many others.

How Much Reliability?

Let us try to identify quantitatively the range of reliability that we have been talking about. Without getting into far more detail than we

have time for today, we cannot state precise figures that will be meaningful to a wide variety of people. But we shall probably find remarkable agreement on the general range of accuracy desired for many measurements. Let us review our target accuracies within the context of the identification of your general requirements.

First, and most crudely, monitor instruments must be adjusted for proper gain setting. A ten percent measurement here is usually satisfactory. It need be only on a relative basis in most instances.

Then, the proper operation of the instrument must be verified from time to time. For such a purpose, 20% stability is all that is required, typically.

If more than one detector is involved, as in an array, then the gains of all channels must be matched for optimum system performance. 2-3% relative accuracy is useful here.

Very frequently, the data generated is to be compared with some later, more recent data. Process monitoring and/or control imply a long-term norm. The earth is observed remotely, frequently to monitor time-dependent phenomena, or to assure the absence of a time-dependent phenomenon. In order to determine either, one must operate an observation system whose behavior itself is not significantly time-dependent on a scale with that which one wants to observe.

Temperature measurements to better than a degree are increasingly in demand. Thermal pollution is a growing example. In the laboratory, under carefully controlled conditions, such measurements can be made in a straightforward manner. But how about space where the instrument cannot be "sent back to NBS for calibration", and moreover where it may operate very differently than it does on <u>terra firma</u>.

Many of these processes will be observed with wave-length sorting of some type. The nature of this sorting is frequently of importance, either the non-grayness of the detector, or the effective band-pass of the filter, monochromator, or interferometer. This is one category of performance verification that can be relatively straightforward and well within what can be done. It is frequently treated in too cavalier a fashion, however. Disagreements traceable to such treatment can be severe even here.

The relative fidelity of spectral information obtained, that is the system relative spectral response, can be approached in one of two ways. In one case, all data can be treated as unique and essentially non-intercomparable with data generated by other systems. This approach has been necessary until now, for example, with civilian remote sensing of the earth, because of the differing spectral band-pass of each platform. For such operation, stability of the system must be assessed to 2-5% depending on use. Accuracy here is unimportant, but the utilization of such data is severely restricted. A complete new library of signatures must be generated for each new system.

If consistent systems can be designed, then intercomparable absolute spectral calibrations become very important. In order to insure intercomparability, assurance of relative spectral accuracy must be made to 2-5%. Very possibly 1% measurements will become necessary. Whatever the level for a given purpose, identification of it and verification of its attainment would avoid the necessity for the generation of new spectral signature libraries for each new instrument.

And finally, in the hierarchy of desirable information, certain tasks will require not only stability, but absolute radiometric accuracy. The promise of a synoptic approach to certain global problems that remote earth sensing promises, for example, will not be realized without long-term knowledge of absolute radiometric levels. Although in principle satellites could be intercompared in chain fashion once the stability of individual platforms were assured, in practice such chain measurements become progressively more uncertain.

Down on the ground, there are other examples closer to you in several ways. As you find yourselves increasingly in competition with your American colleagues and ultimately Europeans and the Japanese, you will find that measurements must be intercomparable with confidence if you are not to fritter away valuable energy, and markets, in constant haggling. Moreover, internally you will want to maintain quality control relative to something that is unchanging. Both stability and accuracy to 1-2% over several years will be of national and international importance.

Absolute Accuracy

Because the stability of most optical radiation monitor systems must be assured no matter what the degree of measurement sophistication, determination of absolute accuracy is not such an additional burden as you might assume. If the other aspects of radiation measurement have been addressed seriously, the requirement for absolute accuracy primarily implies additional attention to initial calibration. This is a relatively straightforward fraction of the entire calibration problem. But all aspects of optical radiation measurement require close attention if the desired results are to be obtained.

Initial Information Needed

These measurement goals present you, the American infrared industry, and us, your national laboratory, not only with some strong challenges but with some remarkable opportunities. We have the chance to push back a complex technical frontier, which is what we like to do best at NBS. At the same time we can assist you in areas where many of you are already finding yourselves in difficulty, and the rest of you will be showing up shortly.

But because of the immense variety of directions in which we can turn now, and the resulting questioning that is preceding the establishment of priorities, we must be thinking hard (technical forecasting) in two ways. We must be asking ourselves what are the most valuable ways technically to bring most rapid progress in these extraordinarily complex areas. And at the same time we must be asking ourselves what the benefits will be in non-technical or semi-technical terms. Only then can we select rationally among alternative courses of action. You can help us to help you by working with us in both of these types of activity. The fact that various technical problems become obvious to you is no longer enough. If your problems are to receive the attention they deserve they must be analyzed and communicated effectively with others.

ANTICIPATED DIFFICULTIES

This forecasting is very difficult. It is difficult for several reasons that we might spend a few minutes analyzing, so that we can deal with them more effectively.

In the first place, it's new to many of us. The novelty makes it a more delightful challenge than it would be otherwise, but it makes us relatively inefficient.

Second, when there is a measurement disagreement it's virtually always "the other guy's" problem. We ourselves don't have such problems; it's the other fellow. So it is natural to leave it to him to concern himself with and to find a solution.

Third, when things don't work right, it's typically production control or material quality. How could the measurements be a problem? Well, increasingly your colleagues are finding that they are!

Fourth, talking about one's problems, either personal or professional is just not done! Especially in the commercial world where one's competitors may reap a short-term, but real, benefit from any information about the problems of others.

Fifth, when there are, occasionally, measurement problems recognized as such, then, well, they're the "state-of-the-art". No one can do better, so learn to live with them. Don't try to do something about them. "Sic transit" enthusiasm for improvement.

ANTICIPATED STRENGTHS

So much for the "bad news". Now for the "good". The very restricted nature of your community in the past means that coordinated effort is not strange to you.

Furthermore, since we are in a position to predict many of these problems, we are also in a position to do something about them if we plan intelligently.

And third, there are real economies of development, production and quality control to be had with more reliable measurement.

Fourth, I suspect that many of your customers for the foreseeable future will continue to be in the government, although not in DOD. The opportunities for all of remote sensing, (and "infrared" is remote sensing, almost by definition), are so enormous that government will undoubtedly continue to play a major role. That may not be the best news to you, but at least it means that the opportunity for coordination will be present. Whether this opportunity is seized or not is up to you.

And fifth, we have a new organization set up to identify optical radiation measurement needs, and to see that they are met. It is the "Council for Optical Radiation Measurement". So you have the tools, both to make your problems known and also to bring effective action.

But let's be realistic about what we need now and what we expect to find necessary in the next few years, in terms of accuracy. Let's seize the opportunity to anticipate predictable pitfalls with realistic foresight and then let's plan ahead to avoid them in an economical fashion. The conversion of a developed technology to broader utilization offers us many opportunities it would be a shame to miss.

END

APPLICATIONS OF INFRARED DETECTORS TO CIVILIAN TECHNOLOGY

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Perhaps we could get an insight into the problems which are the subject of this conference if we made a slight change in the title of this talk. Think about a paper on "Applications of Transistors to Civilian Technology", and see if the problem is in the technology . . .

Surprising as it may seem from the title of the conference, infrared technology has been used in civilian applications for many years, and some civilian applications antedate military IR uses. Military technology has sparked some quantum advances in IR technology recently, but the problem is not one of introducing a military art to an economy which has never heard of the art. The problem is one of trying to introduce devices built under subsidy into a free market economy. If you were to ask me, "What civilian applications are there for a forty-element mercury cadmium telluride array?" I would have to answer "none", because no civilian application could conceivably afford to pay the cost of a full-fledged FLIR system. Come to think of it, the Cheyenne helicopter couldn't afford it either, so maybe some of the points I am trying to make are applicable to military business as well as civilian. I don't think there is a real technology transfer problem as such, in which the civilian technical community has to be educated that such a thing as infrared exists; I think that

there is an engineering and marketing problem in building and selling infrared components and systems that will do a job for the user at a price that he can afford. This problem exists not in the civilian world, but in the infrared community, which must re-orient its thinking from military designs, contract research and development, and government selling to the needs of the consumer, be he industrial or individual.

Keeping in mind that all infrared systems must include a detector, let me list some civilian markets for infrared systems, and therefore detectors:

1. Radiation thermometry
2. Spectrophotometry
3. Fault detection and thermal NDT
4. Thermography, medical and other
5. Fire detection
6. Infrared gas analysers
7. Intrusion detectors
8. Remote Sensing

Radiation thermometry has long been a standard industrial method for non-contact temperature sensing in industry, yet even there it has lagged in application. Few people have looked into the uses that radiation thermometry might have for low cost temperature control, even in consumer applications. Spectrophotometry is now a standard chemical analytical tool, and any growth in this market will depend largely on the development of new analytical tools more useful to the chemist than the ones he now has; detector improvements will affect this only as far as they can be cost effective in the total system. Fault detection and thermal non-destructive

testing have long been recognized as areas of great potential, but have suffered from attempts to sell research laboratory instrumentation as industrial tools without providing the applications assistance that the user requires. Medical thermography has the peculiar problems associated with all medical instrumentation, along with the same problems experienced by NDT systems. Fire detection and intrusion detection are potentially rewarding areas, especially with the growing concern for personal safety in the cities; here also the economic factors become all important. Gas analysis promises to be a booming area in the near future with the concern for pollution control. Remote sensing is almost not a civilian activity, since by far the largest fraction of it will continue to be performed under government subsidy, and even where it is not it will be purchased by the user as a service, rather than a product. Now, in all these market areas, the end user does not buy a detector; he buys a system with a detector in it, so it is the system manufacturers which are most directly affected by detectors.

The first item that the manufacturer will be worried about is the cost of the device. Possibly one of the failures of detector producers trying to get into the civilian market is the failure to recognize the large number of multipliers that appear between the initial parts cost and the final selling price. Take the case of an intrusion detector planned for the commercial market. If the marketing people come back after their studies and tell engineering that if the price is over $150 it won't sell, it

doesn't require much deep analysis to see that the detector cost can't be much over $10, and that if such a detector isn't found, the system will never be built. Furthermore, if there is a selection of ten dollar detectors, the one chosen will be the one that doesn't require an additional $5 or $10 in components to build a superb low noise amplifier and a highly regulated and filtered bias supply.

For manufacturers selling to the industrial market, the cost of the device to the user becomes an important point. The customer will usually be able to calculate the cost of operation and maintenance, which often over the lifetime of an instrument may add up to more than the purchase price. The changes of a liquid helium cooled detector being used are small, because there are very few plants that will invest in the training of a technician to transfer helium and in stocking helium. Even liquid nitrogen cooled detectors meet with a great deal of resistance, in spite of the low cost of the cryogen, because the people involved in production and quality control dislike the necessity of stocking liquid nitrogen, refilling Dewars, worrying about Dewars that go soft, and having to suffer down-time if the system happens to run out of nitrogen.

Reliability is a common requirement to both the military and the civilian markets. Industrial applications often subject infrared equipment to environments equally as severe as military environments. The difference is that the commercial market is not willing to pay the same premium as the military for reliability, though the requirement is equally great. The impact of poor

reliability on the manufacturer is usually greater in the civilian market than in the military. If a military system malfunctions in the field, it may get thrown away without anyone ever knowing about it. If an industrial system malfunctions and shuts down a production line, then everybody hears about it quickly, especially the manufacturer. From the detector producer's view point, reliability may have to be built into the detector in unusual ways. For example, radiometers used to control induction heaters must have detectors that function reliably and accurately in very intense radiation fields. One case I know of is a radiometer that was operating 6 feet away from a half megawatt 450 kHz generator providing welding power on one side and a one megawatt 3 kHz generator providing annealing power on the other side. In situations such as these, detector parameters such as impedance and detector construction which minimize RFI pickup become more important than D*.

Since no system is perfectly reliable, maintenance must be considered, and maintainability built into the system, including the detector. If the detector fails, it should be capable of being replaced by an unskilled maintenance man, not a highly-trained electro-optical technician. The detector must be packaged (and the instrument designed to make use of the package) so that the detector is self-aligning as much as possible when replaced. Special handling during replacement and storage should be avoided. Generally the packaging considerations which help maintainability will also help reliability, and if one is violated, both tend to suffer. In one case a manufacturer built a system using an open flake detector and sold it OEM to a distributor. Shoftly after the

expiration of the warranty period, the detectors began failing, and the distributor found that it was very difficult for his repair technicians to replace the detector. That distributor is now looking for a new supplier of the system.

Only part of the detector problem is under the control of the detector manufacturer. Since he has to stay in business, he has to make the detectors that his customers call for, and therefore the demand for detectors has to be based on designs that reflect the needs of the civilian market rather than the military market. In many cases, there has to be a re-orientation of design philosophy on the part of the user, which ultimately will lead to wider acceptance of infrared instruments in the civilian market and therefore to wider sales of detectors. For example, in every IRIS meeting there is at least one paper re-hashing the old argument over which band is better to work in, the 3 - 5 or the 8 - 14 micron region. For the majority of civilian applications, these and similar arguments are irrelevant, since the ranges are normally short enough so that atmospheric transmission is a minor factor. Instead of worrying about windows, the system designer should worry about matching the detector to the spectral radiance of his source. Along with this goes the choice of specifying the best detector possible, or of working on the rest of the system to bring up the signal to noise ratio. In most cases, I think that economics will show that you can get a much greater return by working on the optics and the electronics than you can from a super detector. Add to this the problem of being able to procure detectors of the highest specifications when you need them for manufacture, and the answer

becomes clear. (This last situation has been faced by many people when they designed systems around detector specifications taken from wall charts). Most infrared systems are amplifier noise limited rather than detector noise limited, and the superior D* detector will not add to the system performance without an expensive electronics design job. Nevertheless, there will always be infrared systems on the civilian market that will require the ultimate in detector performance. Remote sensing scanners, real-time thermography systems, and spectrophotometers are some, when they are being used at the limits of their performance.

Another hangover from military systems work that tends to drive detector prices up and detector usage down is over-design of the system for the application, or its equivalent of trying to sell more system than the customer needs. The military is always crying for higher, farther, faster; the customer is asking will it do my job at a price I can afford. How many industrial thermography applications could be handled without requiring a real-time display, and therefore could use a detector with a lower time constant? How many non-destructive testing applications could be done with only single axis scanning, or in some cases no scanning at all? Yet we find in products on the market the same state of the art emphasis that we find in the military. This creates a positive feedback situation in which the designer specifies state of the art detectors for state of the art systems to the detector manufacturer, causing the detector manufacturer to concentrate on producing those devices which are the most costly to make and the least likely to be available in

reliable supply. For widespread application, the detector manufacturers should instead concentrate on making those detectors which will do an adequate job for the volume applications, and then work on their production techniques to bring the price of the detectors down to the point where they can be thought of as electro-optical components rather than special purpose devices. Still, if there is little call for this approach, there is little incentive for the manufacturer to invest his time and money in the development of production instead of the development of newer and different devices.

I suppose that it would be useful to list the tvpes of detectors that appear to have potential for wide scale use in civilian applications. First of all are the thermal detectors; while this class of detectors (thermopiles, thermistor bolometers, and pyroelectric detector), do not have the detectivity and time constant that can handle a large number of real-time imaging properties, they can be used for a variety of radiometric uses while adding relatively low cost to the system. In most civilian applications the low D* of the detectors is more than compensated for bv their wide spectral bandwidth. Of these three types of detectors, we can expect to see the thermopiles find wide use in radiometric and temperature control applications, primarily because of their self-generating feature which allows them to be used simply with modern low noise IC's and because they can be made at low cost through thin film techniques. The pyroelectric detectors will find more use in scanning systems where their shorter time constant will be an advantage. Thermistor bolometers, though the most widely used in the past, will find

decreasing use because of insoluble 1/f noise problems and the requirements for a quiet bias supply.

Secondly, among the photon detectors it seems to me that there is no question that the lead salt detectors will continue to maintain their lead. This is particularly true because of recent advances in passivation of these detectors, especially lead selenides,which have greatly improved their stability without adding much to their price. For applications where short wavelength response is adequate, room temperature and thermoelectrically cooled PbSe would seem to have the best price / performanee ratio for the near future. Recently some more manufacturers have introduced InAs photodiode detectors, but so far they are not competitive except in applications where severe RFI prevents the use of PbSe. The lead salt detectors can also be produced in volume at relatively low cost through the use of thin film techniques.

Among the more sophisticated detectors, used in the higher price systems such as real-time thermography systems, I think that the near future will see a definite swing to the tri-metal detectors. Of the two types of tri-metals, it is difficult to predict which will turn out to be the definitive 77^{o} K 8-14 detector, but if I had to choose at this time I would pick PbSnTe. If the cost of larger band gap alloy detectors could come down to the point where they would be competitive with PbSe, either for the lead - tin salt detectors or for mercury - cadmium telluride, then they definitely would capture the market. However, metallurgical problems in producing the single crystal material will probably prevent this from ever happening. For large volume applications, no

detector that requires an external cryogenic system (other than thermoelectric cooling)will ever be suitable, at least until such time as the manufacturers of close cycle refrigerators can produce (without tongue in cheek) refrigerators that will operate for thousands of hours in adverse environments and can be maintained and repaired by unskilled personnel.

Another class of detectors that has potential, but no demonstrated performance to date, are thermoelectrically cooled InSb photovoltaic detectors. If these can be brought to the stage where they show adequate D* and reliability with one or two stages of thermoelectric cooling, then they will become very competitive with other types of detectors for high performance applications. Related to this type, and somewhat neglected to date, are room temperature InSb photoconductive detectors. These can be most useful for low time constant industrial applications, even for applications involving temperature radiation near 300° K. If you note than the cutoff wavelength for InSb at 300° K is past 7 µm and that most industrial applications are at short range, then the low D* of 10^8 can be compensated for by the increased spectral bandwidth.

After all this verbiage I should try to come out with some concrete suggestions. These suggestions are directed to both the manufacturers of detectors and the users of detectors (manufacturers of infrared systems):

To the User:

- Try to standardize on a minimal number of detector types and configurations, including packages.

- Look for volume applications which could justify quantity production.
- Learn how to live within price - performance limitations.
- Work with the manufacturer of detectors on packaging and similar considerations which will make detectors directly interchangeable for repair.
- Don't expect the detector to solve all the system problems for you.

To the Manufacturer:

- Try to standardize on a minimal number of detector types and configurations, including packages.
- Don't display specmanship; give the user an honest picture of the performance parameters, including production spreads in tolerances.
- Be prepared to produce and deliver at a price.
- Don't chase after the state of the art, but work on production techniques.
- Stand behind the product; work to insure its reliability, and if it fails, make good.
- Keep the standard products, as they are determined with the users, on the shelf for quick delivery.
- Provide applications assistance for those customers not immediately skilled in the state of the infrared art.
- Keep the cost low.

CIVILIAN APPLICATIONS OF INFRARED COATING TECHNOLOGY

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Technical spin-offs from military and space efforts frequently are a topic of conversation between those of us engaged in aerospace and Department of Defense related work and the public. The Infrared Information Symposium has traditionally addressed itself primarily to the military applications of infrared technology. There exists, however, evidence that knowledge from military applications can be applied to non-military government and civilian requirements.

The subject matter of this paper will deal with the application of experiences gained from military work to civilian requirements; the differences between the two applications; what affects filter costs; and; finally, what the most promising civilian markets for infrared filters are today.

I would like to begin by discussing the differences between military and civilian coating requirements for infrared filters.

1. The first difference which immediately comes to mind is one of cost. Definitely the military will negotiate cost-performance trade-offs; however, because military missions are very costly, performance is the key factor, in most cases, and usually is not compromised. On the other hand, in civilian applications, a closer look must be given to cost-performance trade-offs, because the civilian market is very cost-conscious.

2. Military programs generally span years of time, whereas civilian manufacturers move quickly to exploit a market because of competition in order to have a marketable product to coincide with the need for the product. Hence, the time from design concept to a marketable item is shortened for items for the civilian market. Therefore, once assembly lines are in production, delivery of components is critical in order to avoid costly shut-downs and/or delays.

3. We are all aware that hardware supplied for military contracts must conform to military specifications. The proliferation of government regulations, covering every minute detail of the manufacturer's process, is absent in the civilian market. Also absent, of course, is the confidential/secret classification of specifications. It must be pointed out, however, that civilian customer specifications must be considered proprietary and must be guarded as such.

4. An exception that must be noted in relation to the differences I have been talking about concerns non-military government applications for such agencies as NASA and NOAA (National Oceanic and Atmospheric Administration). Although NOAA, NASA and other government non-military agencies cannot be considered strictly civilian or commercial, they are indeed non-DOD oriented. However, except for classifications, all of the procedures established for military contracts are replaced with similar procedures generated by the agency involved.

There is a difference between the coating requirements of the various agencies discussed and strictly commercial and/or civilian applications. The DOD, NASA and NOAA type requirements continually strain state-of-the-art coating knowledge and demand heavy investment in R&D effort. Following are a few examples of such requirements to which we are presently working:

A. Center wavelength tolerances to ±0.1%
B. Half-bandwidths of less than .3% of center wavelength
C. Attenuation levels of 10^{-5} to 10^{-6}
D. Filter operation temperatures to 9°K
E. Extremely fast optical systems with off-axis applications
F. Demands for higher and higher transmission and reflectance values (up to 99% transmittance in some FLIR applications and 99.8% reflectance for laser applications).

Not only do these requirements necessitate a heavy investment in Engineering, but they require expensive measurement techniques and a more than modest investment in measuring equipment. It is economically unfeasible at this time to apply such levels of performance to products for strictly commercial applications.

A problem facing the coating supplier is how to furnish infrared coatings which require a high overhead facility to government agencies and also be able to provide the commercial market with economical infrared coatings. In the non-infrared area, OCLI has solved this problem by creating a commercial division which services only the civilian market. This division is equipped with extremely large batch coaters and a multilayer automatic continuous coating machine. However, the technology and sophisticated equipment needed for infrared coatings preclude their being produced, at the present time, by our commercial division. How then is the commercial market exploited? Fortunately, the problem is not as difficult as it may seem as long as the requirements of all markets are understood.

Although the IRIS has not addressed itself to infrared civilian applications in the past, infrared coating sales for this market have been steadily increasing, so some of the problems of providing componets for commercial applicatons have been met and solved. It is worthwhile to review the experiences gained from military work which are directly applicable to civilian and government non-military needs. First of all, durable coatings have been developed to meet very strict environmental requirements of military specifications. For instance, most infrared filter coatings must meet humidity, abrasion and salt fog requirements of Military Specification MIL-C-657A. They must also be able to withstand the adhesion requirements of MIL-STD-810B for ten day humidity and temperature cycling. Other related specifications applicable are those for surface quality and resistance to cleaning solvents. The commercial handling of filters is different from the military handling of filters; by necessity, commercial infrared coatings have to be able

to withstand the conditions that prevail in an assembly line atmosphere. The knowledge acquired from experience in producing infrared coatings that pass the tests of the various military requirements has aided us in developing coatings which can easily withstand the rigors of assembly line procedures.

Techniques have been developed for low-cost volume production of filters for missile seeker heads with batch-to-batch repeatability and uniformity of specifications within a single batch. This is the one military application wherein costs and volume production have played a major role in the procurement of infrared filters. Successful design and application of special tooling were required to achieve these large volume capabilities and to assure uniformity of coatings on curved surfaces and on very large and/or small parts. Coating deposition control techniques for maintaining extremely tight wavelength tolerances have also been developed from our experience with military oriented products. Requirements of ±1/2 wavenumber tolerances for filters centered at 650 wavenumbers are becoming more common. Extremely tight wavelength tolerances of this nature, however, are extremely uneconomical for volume production with the present techniques. Until more advances are made in coating deposition controls, such as perhaps computer-contolled coating machines and a corresponding increase in coating yields, very tight tolerances on filters will remain economically unfeasible for civilian applications.

Infrared military applications over the years have necessitated the evolvement of a vast array of coating designs which are now available for civilian and non-military government applications. The development of these coatings would not have been economically feasible for a civilian market only.

Optical shop fabrication techniques have had to be developed to meet the unique problems of infrared coatings as applied to military requirements. These techniques include capabilities for the low-cost, volume fabrication of infrared substrates and the sizing of highly stressed coated substrates. The latter development is of extreme importance in low-cost fabrication of infrared filters for it allows the coating of very large substrates and sizing them to customer-required dimensions after coating. This process eliminates the problem of trying to tool up to accommodate small substrates in fairly large capacity coating machines.

Factors that affect cost must be understood by the potential users of infrared coatings. A big factor is that present technology and equipment is not sufficiently advanced for mass production of infrared filters by techniques of automation such as that offered by the multi-layer automatic continuous coater used for non-infrared coatings. Therefore, the coating process must remain a batch process for the present. Working within the limitations of this process, low unit cost can be achieved through efficient manufacturing processes, which are the manufacturers responsibility, and by volume production which is, of course, the customer's problem.

There are other considerations that affect the cost of infrared filters. For instance, the size and shape of the substrate material for the filter is of considerable importance. Filters can be coated to size but often this represents the most expensive method of manufacture; however, for circular shapes, extremely thin substrates, and certain coating applications, this is the only way that the filter can be coated. If the substrate is rectangular and dimensions are of the order of 3 to 6 millimeters, it is probably more economical to size the filter after coating. Hence, the smaller the filter can be, within the bounds of assembly and handling, the lower the unit cost.

However, in either of the above cases, all physical tolerances should be well within volume production/fabrication tolerances, in other words, within ±0.005 to 0.010 of an inch. The substrate thickness should also be chosen to minimize fabrication cost. This can be accomplished by using materials which can be purchased to standard thicknesses directly from a supplier of infrared substrate materials. Such things as substrate quality, flatness and parallelism requirements add to the manufacturing costs. These factors should not be specified unless they are absolutely essential to the application of the filter. Instead, the standard commercial tolerances offered by the manufacturer should be considered and used if at all possible.

The substrate material itself should be selected so that the spectral response characteristics of the filter coating are maximized. However, structural and attenuation requirements also play a role in the substrate selection. For example, for filters in the 2 to 5 micron region, silicon or germanium are preferable for spectral response and cost advantage, but those materials will not be suitable if attenuation to longer wavelengths, say 50 microns, is required. Hence, synthetic sapphire must be used at an increase in both raw material and fabrication costs.

Over-specifying filter requirements is frequently a major cause of high filter costs. This in an area in which there should be good communications between supplier and customer. The requirements should be discussed so that, when specifications are formalized, they will be written in such a fashion as to minimize manufacturing costs. There are many ways of specifying a filter, but particular attention should be given to the following:

1. When specifying center wavelength, half-power points or cut-on and cut-off points, all effort should be made to keep the tolerances of these parameters to within ±2% of the particular wavelength involved. This is a normal production tolerence for infrared filters. Decreasing the tolerances, to say, ±1%, adds from 10 to 20% to the unit cost of a filter. The additional cost is a result of reduced yields, even with the best coating controls.

2. Cut-on and cut-off slopes should not be specified to less than 6% for wide bandpass filters and not less than 3% for narrow bandpass filters.

3. For out-of-band attenuation requirements, normal production can achieve 0.1% transmission. Additional attenuation requires more coating time and materials and additional expenditures of measuring time with sophisticated spectrophotometric equipment. Therefore, out-of-band transmission requirements should be kept to the 0.1% level for low unit cost.

4. In-band transmission requirements should also be within normal production capabilities. Since this value is a function of the type of filter, it is advisable to refer to information published by filter manufacturers. The "Infrared Handbook", published by Optical Coating Laboratory, outlines typical performance characteristics for various types of infrared fiters. For example, this publication outlines the minimum peak transmittance for square bandpass filters as a function of nominal half-bandwidth and center wavelength, with remarks on attenuation levels and wavelength ranges.

5. Quality contol and final inspection requirements can also be a source of high filter costs, and the end user of a filter should avoid 100% inspection. Lot acceptance should be based on sampling techniques or functional testing. Functional testing often offers significant advantages for reducing filter costs. The method works as the name implies: a mock-up of the instrument, or the actual instrument itself, is used by the coating manufacturer to functionally test the filter. Based upon instrument performance, the filter is either accepted or rejected - a go or no-go situation. This can also result in the assembly and test of sub-assemblies at the coating manufacturer's facility, with further cost savings to the customer.

6. Finally, infrared filters are sensitive to both temperature and angle of incidence. Although the effect is reversible, center wavelength will shift with changes in temperature and for angles of incidence away from the normal. Filters can be designed for operation at other than ambient temperature and normal incidence, but these requirements increase filter costs, for the net effect is a reduction of manufacturing tolerances and increased final inspection costs.

The factors that we have been discussing all combine to affect production yields. If adequate manufacturing tolerances are allowed and consideration is given to the filter specifications, the chances of obtaining high yields and corresponding low unit costs can be maximized.

I would now like to discuss some of the identifiable applications for infrared filters in non-military markets. First, attention should be given to applications for the non-military government market which includes such agencies as NASA and NOAA. Although this is not truly a civilian market, it has not been discussed recently at IRIS. Since many of our IRIS members are deeply involved with these agencies which represent a significant portion of the infrared filter market, the market should be mentioned briefly. The requirements for filters stem from work involved in the investigation of the atmosphere which utilizes high resolution radiometers. Specifications for filters for use in experiments continually require significant state-of-the-art process improvements from the coating supplier. These programs require high-cost, low volume applications of infrared technology. Although the market cannot be considered to be a civilian market, its infrared technological applications directly benefit the civilian population by giving it an improved capability for weather forecasting. Typical examples are the Vertical Temperature Profile Radiometer, the Infrared Temperature Profile Radiometer, and the High Resolution Infrared Sounder, all to be used on the Nimbus Satellite series. The atmospheric Operational Sounder is now under feasibility study for operation with the TIROS series, and is anticipated to be operational by 1975. Another program which has received wide publicity is the Earth Resources Technology Satellite (ERTS), which also utilizes infrared radiometers.

Let us now turn our attention to those markets which have been identified as strictly commercial, civilian markets, limiting them to those which require the most significant volume of infrared filters. For some years now, order separation filters for a spectrophotometers have been a very large part of the market for infrared filters. These filters are used to suppress lower wave length orders of grating monochrometers. Suppression is accomplished by using long wavepass filters with extremely low transmission levels below the cut-on wavelength. A filter which has been very successfully used for this application

is the circular variable filter. Circular variable filters are optical interference coatings, vacuum-deposited on circular substrates so that the center wavelength location of a bandpass filter or the cut-on wavelength of a long wavepass filter varies linearly with the physical angle of rotation. In the standard filter configuration, the cut-on wavelength of a long wavepass CVF would vary linearly from λ at zero degrees to 2λ at 180 degrees and back to λ at 0 degrees. Hence, for the order separation application, the CVF is tracked with the grating to suppress lower wavelength orders thereby maximizing the transmittance at the wavelength of interest.

A square bandpass CVF can provide virtually constant resolution over a particular wavelength range. In a scanning mode, for instance, it can readily be used as a monochrometer. In this application, the filter provides rapid scanning of a wavelength range by physical rotation, is easily calibrated and requires little maintenance and no optical alignment. These features have made it attractive as a low cost monochrometer for such applications as gas analyzing.

Other applications finding uses for infrared filters are non-contact temperature measuring devices, burglar-intrusion alarms, and instruments for production line measuring of the thickness of thin polymer materials.

There are undoubtedly many other applications for infrared filters, but those mentioned probably represent the largest identifiable markets at the present. The most exciting and perhaps largest potential application for infrared filters, however, exists in the area of air pollution detection. Because of its large potential for infrared filters, it is worthwile to examine this market in more detail.

We are all aware of the furor over the discharge of pollutants into our atmosphere by transportation and factories and that the pollutants represent serious known or suspected hazards to human health. These pollutants are sulphur oxides, hydro carbons, carbon monoxide, nitrogen oxides and photo-chemical materials, commonly referred to as smog. The effective contol of these emissions through national and local regulations will require detection instrumentation. Therefore, there exists a market for three areas of measurement instrumentation: ambient level monitoring, stationary source emission, and automobile exhaust emission.

It is estimated that pollution control requirements could provide a 1/2 billion dollar market for air pollution measuring equipment. Of these, the auto exhaust analyzer has the greatest volume application for infrared filters. The detection and measurement of the major auto emission gases, hydro carbons and carbon monoxide, can be made using infrared techniques. The technique is based on the absorption of infrared energy at selected wavelengths of different gases. It employs an infrared source, a wavelength selector, (a filter) and a detector. There are other techniques, to be sure, and any one technique will be marketable, depending on the allowable emission levels set by such agencies as the Environmental Protection Agency and the ability of the industry to manufacture an instrument acceptable to the end users. The end users of such devices could be automobile manufacturers and dealers, service stations, automobile manufacturers and dealers, service stations, automobile repair shops and state inspection stations. The potential market for these devices is a highly controversial topic at this moment. However, conservative estimates put this figure at 150 million dollars for the decade 1970 to 1980. This estimate assumes that service stations and auto repair facilities will purchase air pollution measuring instrumentation and that an annual nationwide auto exhaust measurement program will be adopted.

Although it is assumed that there will be a market for a moderately expensive instrument for automobile manufacturers and their dealers and for the state inspection stations, the industry segment of the market, which is the service station portion, may not evolve unless instrumentation manufacturers can develop a low-cost system, perhaps in the vicinity of $500 for a simple package. This, then, places a very severe cost limitation on components such as filters. Whereas the most sensitive, hence expensive, instrument selling for under $3,000 can use a moderately expensive filter, the low priced service station instrument, selling for $500 to $1,000, will require a reduced filter expenditure in the same ratio as the two instrument prices. The mass production of these filters has been shown to be feasible, with the price largely dependent on the size, since the manufacturing tolerances have been quite uniform at ±1% for most applications. The half-bandwidth, slopes and attenuation requirements are easily within standard narrow band-pass filter designs and production in thousands of units has been accomplished in the price range needed for a low cost instrument. In all cases, success of the undertaking was based on excellent communications between the filter supplier and the end user to arrive at workable specifications with an acceptable manufacturing cost.

Summarizing, the experience acquired in supplying infrared filters for DOD-oriented applications has been successfully used in civilian applications. Although applications in the civilian market will continue, the only significant new market which can be identified is in the area of air pollution monitoring. However, it is hoped that the success of this venture will open up new markets for the infrared filter.

CRYOGENICS - APPLICATIONS AND THE CIVILIAN MARKET*

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First of all, my background is neither in optical infrared physics nor in cryogenics. I'm a molecular spectroscopist, but I work for a cryogenics manufacturer. And the second point is that I have only been involved with the cryogenics industry for about three years. But at about that time, at least our segment of that industry seems to have gone through the same sorts of things that you are examining here today. We've got all this great technology that really has some tremendous potential; what do we do with it? Well, we and other companies who are our competitors, have gone through this and we're starting to become more of an applications-oriented industry. There are obviously barriers that have to be broken and you've indicated many of them here today in the Infrared business. But they can be broken. We've started to make some money at it, so it's certainly not a lost cause. And some of the application strides that we have been making with cryogenic equipment are very, very closely allied with some of the areas where you seen to have the expertise, in certain detectors, in filters, and in the ability to sense over broad ranges of the infrared spectrum. With that, let me get into what I have written down.

When Tony LaRocca invited me to present this paper, he asked that it be about cryogenics and discussed broadly what we would talk about. Then he sent me a letter and I feel that I've really got to read these sentences out of it. "In view of the huge cost burden that cryogenics imposes on infrared detectors, you are in the position of having to offer an apology or issuing an ultimatum. The first of these declaration will bring you little sympathy unless you can demonstrate the huge success that a number of IR devices enjoy, despite the cost, because of their great value; or unless you can show that compromises will reduce the cost at the recognizable sacrifice of some performance". That sort of left me a feeling that if I came and talked about either one, it would be like making a suggestion to double the federal income tax. So I'm going to try not to do either. And the paper that I have prepared is sort of an indication of these trends that I started off with.

We've got developmental trends that are taking place in our industry that I think are very closely paralleling your own. But first off, let's talk about that area of cost so we can at least make some definitions. Cryogenic equipment is expensive. And there are lots of different kinds of cryogenic equipment. The least expensive thing that you could buy from CTI that's a whole entity in itself probably costs about one thousand dollars, whereas the most expensive is something like about one and a half million. So we have a pretty good range of equipment that we have to narrow down to talk about. At the present time, we're not the only manufacturers of this kind of equipment either. But there are a number of particular cryogenic components and devices that are particularly used by civilian infrared users. And there are two main types. I'm not talking about the end use right now, but the types of cryogenic systems. There are open and closed cycle systems for want of better terms. And I think we all know what they

*The version of Mr. Carroll's talk presented here was transcribed from a tape recording, with only an absolute minimum of editing.

are. Open cycle systems are merely buckets in which you put liquid nitrogen or liquid helium, either by a crude method or by a relatively sophisticated transfer method. And closed cycle systems are mechanical refrigerators that utilize electrical power, so that you throw a switch and the machine goes ahead and "makes cold". In terms of the economic selling of these devices, there are technical tradeoffs and even convenience and comfort tradeoffs that allow someone to choose one system or the other, because the open cycle system, the slop bucket of liquid helium, for instance, has a relatively low initial cost for cryogenic equipment. When I say relatively low, those are things that sell for something like two thousand to four thousand dollars in unit quanity. Open cycle systems, however, sell more on the order (or at least the ones I'm used to, that are applied to infrared application) five to perhaps nine thousand dollars. So they are starting to build up there. But in terms of operating costs, open cycle systems are rather expensive especially if they utilize continuous quantities of liquid helium. Whereas closed cycle systems really don't have continuum operating costs provided they are reliable. As long as they're just plugged into the wall they are utilizing relatively inexpensive electrical power and not creating a great demand on the long term user. Before we go on, let me show the pictures of these to sort of indicate the magnitude and physical appearance of this equipment.

This is a cutaway drawing (Slide) of a commercially available transfer system. If you can imagine all that piping being connected to at least one point in a liquid helium reservoir, it could be conducted over, provided the thing was vertical and not horizontal, down into the center portions which are simply heat sinks and which, as shown in the cutaway, are radiation shielded and finally vacuum contained. And in the next slide (Slide)we have a photograph of that same equipment. I'm sorry that I don't have a size indicator in there, but that whole device is perhaps 14 or 15 inches long. At its widest point on the dewar, it is something like three inches wide. And you can see there is optical access to it. Compared against this, is typically what we see as a civilian closed-cycle cooler and its physical appearance in the next slide. (Slide) This is only the cooling head portion of a particular system that we manufacture. It does require a compressor that is not shown. This is the business end that goes into an infrared spectrophotometer, and the device is a mechanical refrigerator with its attendant drive motor; it has a built-out vacuum shroud, and sample chamber and valving equipment around it.

Closed cycle coolers for civilian laboratory applications are lower in price than their military counterparts. This is largely because of greater allowable latitude in the cost elements. I get the impression from having heard the previous papers that most people here are familiar with FLIR systems and the type of closed cycle refrigerators which might have been applied to these detector arrays. We have found in the civilian refrigerators in the same size that we are making, that we're saving a lot of money in these particular areas. First, there is the relative freedom that is given to the designer regarding packaging and component selection. We have end uses that we have to meet, given temperature ranges, given heat dissipation at a particular temperature, and an overall size. But those are only the frameworks. Then, of course, there is the choice of a refrigeration cycle. Those are the only real, hard-line parameters for the systems that we build. The designer can go ahead and pick and choose vacuum and helium components and electrical components that suit the needs for a given price.

Now, the restrictions placed on the operating environment for the machine used in the civilian applications are typically far less stringent than those used by military equipment. Military equipment that we have seen has very high and very low external operating temperature environments, and they also must meet mil spec standards for things like salt, fog and corrosion, fungus and so forth. This is not true for laboratory equipment. All that is being sold ultimately for the civilian infrared cryo-coolers is a statement of reliability, and the faith that the user can ultimately depend on the manufacturer to induce. The third thing is commonality. The system that you saw on the last slide is one of about four or five systems we make for civilian usage. But they are all variations on a theme. We can go ahead and take the same essential cooling equipment and apply it to those four and five specific systems where we have identifiable markets. We can afford that kind of commonality and, of course, each individual market is bearing part of the cost of development and the marketing and selling cost for the overall product line that we have to sell. And that brings these things down in price.

Now, all of that talk about cost and price doesn't help much unless I indicate sort of what these costs and prices are. The evolution of one particular refrigerator of ours went like this. In the first place we had a four-hundred-cycle airborne military Gifford-McMahon cycle cooler. That's our stock in trade. The Gifford-McMahon cycle is something that we've been in business with a long time. A single copy of that system might cost you, if you were to buy one, almost 12 thousand dollars, because of the mil spec characteristics. Now, we went in this evolutionary process and built a 60-cycle version on the same machine. The 60-cycle version just simply means that it can operate on 60-cycle power, but could also meet the same mil spec standards that our airborne systems could meet. The cost of that system, were you to buy one (rather the price to you, were you to buy a single one) would have been 11 thousand dollars, or virtually no difference from its airborne counterpart. The model 20, which I'm going to show on a slide in just a moment, is the civilian name for a civilianized version of that same 60-cycle machine built with the latitude that I mentioned just a moment ago having been given to the designer. And the cost for that system is around, in single copy, six thousand dollars. So appreciable price or cost savings are starting to accrue to the people that can buy these. Now these refrigerators that we built are extremely sensitive to economies of volume and economies of scale, and when they are produced in single lots, even though there is some commonality in them, and they have to be tailored for applications, the price won't vary much from those six thousand dollar levels. And again you are probably all thinking right now, "that's a hell of a price to pay if I had to use that to cool an infrared detector". If you wanted to buy a hundred of those, you could probably halve the price that you would pay for that, or at least come close to it. Obviously, that's not an official quotation. But it is very true if they can be designed so that they can be delivered according to a given schedule. The economies of scale would accrue to us and then accrue out into the open market place. Let me show you what some of these refrigerators are.

The slide that's now being shown (Slide) is a totally enclosed package showing a military airborne 400-cycle cooler that does include it's compressor. That's about a 22-degree, one-watt machine. And the next slide. (Slide) These two cold heads are Gifford-McMahon cycle machines and were the start of the evolutionary process that I described. The one on the left is a 1-watt 26°K machine that has to be run by a separate compressor and is built for airborne applications, and that's the sort of thing, in single copy, that would sell for

12 thousand dollars. Its friend on the right hand side is something like a 3-watt, 77° mechanical cooler using the same refrigeration cycle, but again the economy of lopping off part of the cylinder and cutting down its size just simply doesn't appreciate. That machine is about the same price in the same quantities. Now the next slide (Slide) is a cold head for the model 20 that I mentioned. That's our basic civilianized one-watt (right now that's a 1 1/2-watt) 19° machine (because its changed internally a bit). That's the machine that sells for approximately six thousand dollars and we're finding a very great but rather diverse market for that machine. And again, that economy has accrued simply because we're adopting the technology that was developed for the closed cycle airborne systems but with the latitude to put the design parameters that we feel are economical for production and for what a particular market will bear.

I'd like to put off now, until perhaps a question session, the nature of the cryogenic equipment itself. And I'd like to talk particularly now about an application. In several papers that have gone before, I've heard people talk about infrared absorption spectrometry. I'd like to initially offer a reinforcement of what Mr. Limperis said in his paper this morning. He indicated that there is an existing 30 million dollar market for infrared spectrometers with an annual yearly sales figure of a continuing 30 million dollars. In part of our application-seeking, much as you are doing right now, to find viable markets for our cryogenics, we researched this market rather thoroughly because we had had some previous sales into the market. Right now there are about 12 thousand infrared spectrometers (and these are things that have a net price of about 18 thousand dollars) in existence. And the annual sales of these spectrometers, according to our market surveys, are in the order to 8 to 12 hundred systems. Very good reasons for this. If you walk into any laboratory, or your own if you're in a large firm and have an analytical laboratory, you'll see many different spectrometers. UV, visible absorption spectrometers, and if you're wealthy, you may have an ESR spectrometer. You might have a lot of things like that. But almost undoubtedly if your firm deals at all with organic chemicals, any one of the three hundred or four hundred thousand known organic compounds, you will have somewhere in your environs an infrared absorption spectrophotometer. You can do more with that one single piece of equipment to define the nature, the chemistry and the structure of a particular molecular than you can with any other single piece of equipment. There are overlaps, of course, but that is the most important spectrometric device found in laboratories. And it's not likely to change, because the needs are still there. The needs of defining molecular structure are still very important today. The absorption of infrared radiation in the 2 to 20 micron region is where these are normally working. There is a considerable market in the region out to 50 microns, or out to , say, 33 wave numbers for far infrared, but that's not really an open analytical application field today. It probably will be in the future. So anything that's going to serve that 2- to 20-micron spectrum better is probably going to be useful to the infrared spectroscopist. Now I said that it's important for molecular structure identification. Let me show you what an infrared spectrometer looks like and typical samples for it before we go on. May I have the next slide please.

The slide (Slide) was available only on short term. It obviously plays up our equipment, the closed cycle cooler in the middle, and doesn't do much for the infrared spectrometer, Beckman IR 12. That's typical of the class of spectrometers that are used for high resolution infrared structure determination today. It has a selling price of about 25 thousand and if you could see the physical piece of equipment, the chamber on the right that says "IR 12" is perhaps 2 feet long and about 1 1/2' high. The chamber on the left of which you can only see the left hand wall, stretches for about 4 feet and has the same height. So it's a pretty

hefty piece of equipment. It has to be put into place with a forklift truck when it's put into a laboratory, or by several very rugged and ambitious people. It's a pretty hefty piece of equipment. The next slide shows the typical kinds of samples that an infrared spectrometer looks at. What you're looking at in that loop, not the part held by the fingers but the little thing that looks like a lollipop with a dark edge, is a potassium bromide pellet.

Quite often sample handling is a great difficulty in infrared. It's one that people put up with because you get so much information out of it. If you have a liquid, it's the easiest thing you can analyze in an infrared spectrometer. If you have a solid, and even more particularly, if you have an inorganic material, it's quite often ground for about 12 minutes and then pressed at high pressure into an optically and infrared clear pellet of that particular shape; and there are other materials that are analyzed too. Things are whipped up with oil to make a greasy mull, just so the material under analysis can be held in a convenient position where it can be looked at. So, typically we have that big spectrometer. And in our case, we have to take part of the biggest claim, because our big cooler is used to cool or analyze a very small pellet like that. That's, at maximum, a half an inch in diameter.

What I just said about sample analysis and sample preparation is and has been true for quite some time. Those are classical methods of sample handling in the infrared. The chemistry involved in both industry and in our society today has taken on a radically different climate than it had even 2 years ago. The analytical instrument business, of which infrared is only a part, had its fattest year in sales volumes in 1968. Records were broken, people were getting big raises, they were hiring new salesmen, instruments were going into laboratories where they really were not needed, because the heyday of the space money was still dropping into the instrument field. In 1970, there were more instrument salesmen pumping gas than there were selling instruments. And it's only now that the instrument business has enjoyed a resurgence. And the one thing that has brought it back to life is really the new and renewed replacement interest in infrared absorption spectrophotometry. The applications that are taking all these new instruments and putting more salesmen back to work are, as you might expect, air pollution, the drug business, and also the semiconductor business - - solid state analysis of semiconductors by infrared absorption, and the one other, chemical process kinetics.

The old days of the Solvay cycle in producing sodium carbonate and various other simplified but mechanically complex methods of producing bulk chemicals are really dying out. If you look at common chemical process industry journals today you'll find that by and large there are plants closing all over the United States that made bulk chemicals in this fashion. What are being built now are plants that utilize radically new technology, that don't have the big reaction towers and reaction vessels that people normally associate with the chemical industry. You find the very small and highly sophisticated vessels that can handle things like free radicals or handle molecules that are in a charged or ionic state in their natural environment. So the needs of the industry to analyze these processes and develop them in terms of quality control or economy, or even to identify simply what can be produced by a process, really means that analytical technology has got to be available which can sort of catch a molecule on the fly as it is being produced from a hot ionic source and before it can recombine with something else. So it means that the chemist now-a-days isn't faced with a test tube. He's faced with something else, usually a high field, or a vacuum chamber or something that can grab the charged molecule that doesn't want to exist by itself in nature. And the bulk of his work is falling into the infrared field. So what's happening is that people are taking all of those very expensive, and large numbers of infrared spectrometers

that they have had for a long time, and which essentially have not changed in their technology since their inception in about 1942, and are trying to analyze modern chemical processes with what really is antiquated equipment.

When I say that they are antiquated, that doesn't mean that the infrared spectrophotometer business has sat on its duff for 30 years. Not at all. But what happened very early in the game was that someone devised good infrared monocrometers and they devised double-beam systems which take out some of the onus of looking at erratic sources and so forth and came up with a very workable system indeed.

That system has suited the needs of chemistry let's say over these 30 years, but not its falling a little bit short - both in its ability of handling materials, and in its quantitative nature. Infrared spectra by their very nature today - when I say by their very nature, I mean what can roll off the recorder chart of the spectrometer - are somewhat ambiguous. Even when their computer searches are done on the hundreds or thousands of spectra that can be yielded, usually what's done is that the analyst is faced with the 20 best fits with the spectrum and he makes some calculated guesses at to what he's getting on that chart. So in addition to the sample handling needs, there's also a need for that infrared spectroscopist to have less ambiguity in the data that he's getting. And this is not a pipe dream because there are people responding to this need right now. Their response to the need is taking on some interesting aspects. I mentioned the price of about $25,000 for a high resolution infrared spectrometer. Right now in order to accomplish the needs I just mentioned, rather high speed, rather specific analysis and better data fitting of what the man is getting out, people have come up with interferometric systems. These interferometric systems shorten the time from hours to minutes for an infrared analysis; and they do a little bit at improving because you can signal-average and reduce noise and retrace spectra 30 or 40 times, thus eliminating or reducing the interpretation problems. A typical interferometer... (Ed.Note: this part of the paper was missed in a change of tape. The transcription picks up a minute or so later).

Next slide, please. I mentioned that we produce cryogenic coolers for four different ranges, of four different size characteristics, rather than just take our systems and constantly seek after that illusive $100 cooler that I think everybody would like to have. That (Slide) is the most expensive system we've built and we built that long after our other coolers. That's on the order of, when you have everything fitted onto it, perhaps $10,000 or $11,000. And it is nothing. It doesn't have an end use in itself. It can only be applied to a spectrometer. So you can't even use that thing unless you wheel it up to an infrared spectrometer. Yet we're doing extremely well with that in the semiconductor industry where it does one thing. It provides a convenient and stable reference analysis point at 3 temperatures, only two of them cryogenic, and it does it rapidly and repeatably. And they're paying premium prices to do that kind of thing.

What we've seen in all of this marketing and application to this industry ourselves are that there are future system developments. One of them that I just started to mention is the interferometer system. And this is a system that really should be of interest to everyone here, because it's one of the areas in which people are starting to demand cryogenically cooled solid state detectors rather than what's available to the instrument manufacturer today. Now we don't make detectors and we can't really fill that need, but I'll give you a piece of the marketing information that we derived when we were looking at all of these markets. Our outlets right now are essentially sample coolers in this market (and the reason for that I'll explain in just a moment) which gets up very close

to the manufacturers of the spectrometers. We deal with them frequently. A common question that we've been asked by the 3 largest infrared instrument producers, analytical instrument producers, in the U.S. today (we got this question independently from all three of them) was, "why don't you provide us with a closed cycle cryogenically cooled infrared detector that can sell for $3,000?" Not the $300 that I heard earlier, but $3,000. That's a device that has a closed cycle cooler and an infrared detector. The types of detectors they talk about are unimportant as long as they have a reasonable output for their electronics and can cover that 2 to 20 micron range. Now, the first thing I suppose you'd do if you came to us would be to say, "OK, you've got a $6,000 machine and you want me to give you a detector for a penny so you can put it on the end of your expensive cooler". It doesn't have to be that way at all because the scales that they are talking about for these represents about 900 of those detectors a year. And we got that figure independently from three producers. So there is a market for at least 900, $3,000, end-selling-price, cryogenically closed-cycle cooled infrared detectors. And strictly for the infrared absorption spectrophotometric business. We would be more dubious than we are about those dollars, the dollar selling prices, and actually the OEM prices at which they would have to buy them, which may be perhaps two thirds of that, if we had only heard it from one source. But we got that independently from three separate sources. And after the further exploration we've done on that, we're fully convinced, in our own mind, that that's a very real market. And that also is conservative in that it hasn't explored all of the refit business that could be done with people that currently own large frame, high resolution infrared spectrometers. So we do see a very real, and what could be a rather lucrative market for that sort of thing.

Now, why would they want to go to these kinds of detectors in these rather fancy interferometer systems that cost $85,000? Well, what they are putting into these detectors, what they are building around the entire systems, are essentially sources that are pretty much the state-of-the-art sources, that have been the state-of-the-art infrared sources for the last 10 years. Nernst glowers have been the most common source used in all the spectrometers and they haven't really changed. So you have an acceptable but not highly sophisticated infrared source. The next item you have in the chain of construction of the overall equipment then is a very big infrared monochrometer. Usually very sophisticated and very big. Very sophisticated means that it's got maybe 4 gratings in it to cover the range, and it's got mechanical sine-bar drive equipment to drive each one of the gratings sequentially to give you scanning. And they when you get to the interferometer, of course, you go a step further, and you have a Michaelson Interferometer interposed in the system after the source. Then, somewhere in the system, you get just an open space which is the sample compartment, probably a double beaming system, and then the attendant detector and electronics to read out all of the signals. Now in the middle of the system, the optical parts of it, the sophistication has come up to answer some of the needs of the infrared spectroscopists. But what hasn't happened is that the sources haven't really improved nor have the detectors. They work with pneumatic Golay detectors, and they are not satisfied because the detectors are sluggish and lazy in their response. That's one of the things that indicates that a high resolution infrared scan normally takes about 2 hours rather than a matter of minutes. The same is true of bolometers and thermocouples except that they are not usually bad-mouthed as much as a Golay detector is. And this is the sort of thing that makes the

spectroscopist look wistfully at a different kind of detector with real time response. And then, of course, in the spectroscopic journals, there is significant amount, not a lot, but a significant amount of reference to cooled solid-state infrared detectors to allow people to want to investigate what they can get from them. On top of that, of course, they would like to have some improvement in the source. But the infrared equipment designers, let alone the ultimate end user who doesn't really want to be an expert on how to build the spectrophotometer, are not really aware to where they go to get these sorts of things. The interferometer systems are going to be in laboratories for years to come. Ultimately, as people start to get more money or the economy recovers more, or NSF puts out more money, people will tend to buy less and less monochromatic, dispersion infrared spectrometers, and they will start buying interferometer systems at a pretty tough price. And with business being what it is, these will probably reduce in price as time goes on, unless the technology advances at the same time. These things usually tend to be complementary and we're pretty convinced that the infrared spectrometer of the future is going to be a package, less electronics, that will be relatively small.

We've seen some literally astonishing results, not many of them, but astonishing nevertheless, resulting from these newer approaches. And I am talking now about tunable diode lasers. The tunable diode lasers are to the point now where they can be scanned. They can put out the infrared spectrum over the entire range of analytical interest; in fact, more than the entire range. They can be made to put out up to 50 microns, and that satisfies the needs of the far infrared spectroscopist as well. They are available now. They have already been applied to infrared spectroscopy and I'll show you in just a moment just what they can do and why they represent such an enormous potential market, not only for you infrared types but us cryogenic types. Next slide, please.

We're not in the tunable diode laser making business. This is given to us through the courtesy of the detector science group at Arthur D. Little who makes the things. That whole thing between the fingers is largely heat sink and electrode. There's an electrode at the top and an electrode at the bottom, an insolater in between, and there's a gap right in here where the arrow is pointing. Where the arrow is pointing there is roughly a half millimeter tunable diode laser, which can put out the spectrum that we're interested in. The next slide is a larger picture of it. In this picture I guess you can just about see the laser chip itself with the conductive lead going up into the electrode and the insulator around it. And the rest of that material is just simply structural and current carrying equipment that can be used for this sort of small semiconductor device. Slide off, please.

This device, of course, replaces the entire dispersive infrared monochrometer in the dispersive infrared analytical absorption systems, and it also eliminates the interferometer in these new Fourier transform systems that are now available on the market. It also eliminates the Nernst Glower, provides a coherent source of infrared radiation, and allows a scanning ability which is literally staggering when you look at the system parameters of normal spectrometers. Typically the number that's used is that they offer solution capabilities of about ten thousand times over what a high resolution infrared spectrometer can do. That provides more resolution than is actually necessary for the spectroscopist. I've just had a chance to read a preprint of a paper entitled, "Let's solve tunable diode lasers" written by a Dr. J.F. Butler, also at ADL. And in it he gives an ethylene spectrum.

They have applied these, by the way, to the normal finger print region infrared analysis of auto exhaust pollutants. And I had occasion in that paper to look at a spectrum in the 940 to 950 wave number region of ethylene; and the ethylene spectrum that they obtained on a normal high resolution grating spectrometer looks something like that (Ed.Note: at this point the speaker used the blackboard). That's a rather hard to interpret spectrum but it can be used. As I say, this region here is perhaps 950 wave numbers to 940 wave numbers.

The infrared spectroscopist suffers ambiguity when he has to look at multiplet peaks that don't have sufficient resolution to eliminate the band overlap that's obviously present. The magnitude and intensity of the peak is not usually very important. So this background, I've got this drawn upside down by the way, is not really very important. All he really cares about are the peak frequencies. And he'd like that peak frequency to be identifiable to the extent that he can say definitely that's caused by, say, a carbon-to-hydrogen, or a carbon-to-oxygen, change in motion. In examining the same gas cell using, instead of a grating spectrometer, these tunable diode lasers, they took the segment of the spectrum shown in my shaded lines and then scanned this over a total distance of two tenths of a wave number. An in that two tenths of a wave number, expanded so it could be looked at in a visual presentation, they got 89 separate and distinct and easily identifiable absorption bands. That's more information than the spectroscopist could ever use. They could go crazy trying to interpret those bands. But it does define the inherent and enormous capabilities of tunable diode lasers.

One tunable diode laser, as I understand it, won't cover that 2 to 20 micron and certainly not the 2- to 50-micron region that the spectroscopist is interested in. But 10 of them will and 10 of them can be mounted as you saw on a heat sink certainly not much bigger than was shown on the last slide. So you have an infrared source and monochrometer, if you will, that's not bigger than my thumb, which has this tremendous capability. It's fraught with some problems obviously, if you get too much information. What do you want to couple up with this? You've got to have a detector. What is the prime requisite of the detector? It's got to be able to track the scanning sweeps of the laser itself as rapidly or with the same kinds of smooth response, that the output source, the laser itself, is giving. So it would be desirable at least to have as good a detector as you can put into the system. The rest of the system may be electronics for controlling the parameters of the laser itself and examining the output in any one of several different and elegant modes. It also provides much more if you can sweep and scan very carefully like that. Of course, what you can do is use that infrared spectrum for getting unambigious results, free of interference from other species.

Now why are cryogenic people so interested in this? Well, there is a very nice facet that we like very much about tunable diode lasers. They have to use cryogenics. They don't operate except in the range, say, 12 to 77 degrees Kelvin or 100 degrees Kelvin. I'm not too sure of the parameters, but I know that they can't operate at room temperature. There are several methods that are used, four of them I guess, for scanning the laser itself. One of them is temperature and, of course, we'd like that to be the one chosen. Especially if the thing has to be cooled anyway. Now, I wanted to talk about the functional plurality of using a cryogenic system for these various aspects. Before I do I want to make one mention of the nature of sampling that's going on today, because it's going to apply in this functional plurality.

I indicated that there are people using frozen sample techniques to get samples on the fly, and that's something rather new. The technique is not new but its recent application is. It's not very uncommon today in research labs.

But in research laboratories today they are using a technique in infrared called matrix isolation spectroscopy. What this does is get down to pure fundamental vibrations appearing in the infrared spectrum. You do this mechanically by taking the sample, putting it into the vapor phase, and spraying it at an extremely cold substrate, say on the order to 20° Kelvin, in very dilute ratios, say one part of the sample of interest diluted perhaps about 1 to 300 times as much in a weakly interacting gas like argon, nitrogen, or CO2. What happens is that this entire thing freezes then on the cold substrate and if you take certain little pains like annealing the frozen material, what will happen is that you will get isolation of the molecule of interest in a weakly interacting solid, frozen argon let's say. Then you eliminate perhaps 3 of the 4 phemonena that give rise to infrared spectra.

If the molecules can't touch one another, then there can't be intermolecular interaction. Some of the spectrum that you observe in this is due to that intermolecular interaction. You eliminate that. Hydrogen bonding is an effect, bonds that are formed only by the strong dielectric strengths of the hydrogen and hydrogen-like ends, functional groups in the ends of the molecules. If they can't get together, you can't have hydrogen bonds. They would have to be together on the order of 10th of Angstroms in order to create a hydrogen bond. You will eliminate that kind of spectra. If you are aware of what the water spectrum looks like, that virtually eliminates the broad water bands at 3250 wave numbers of 3 thousand odd microns, I guess. And the third thing it does is to cut down the thermal agitation that shows as absorption spectra which are part of the rotational spectrum of the molecule. So what you end with is not infrared spectra like this (on the blackboard) but you typically, if I were drawing it in the same place, obtain ideally some base line with a sharp loss in energy due only to the true vibrations that take place, the fundamental vibrations within the molecules. People are adopting this.

So we see a very big growth area in infrared systems that, from our point of view, use cooling, but also use these technologies. I've reversed the order of importance, obviously. But if you can take a tunable diode laser and use that as the virtually entire spectrometer and you have to cool it anyway, it means you've gone ahead and taken the sledge hammer cooling approach and forced it into the system necessary to perform the analysis. If you've got the cooling there anyway and cooling applied only to a device that's consuming perhaps 100 milliwatts of heat dissipation, and you've got all this excess cooling, which you will tend to have, why not use it to cool the infrared detector? And even more than that, why not use matrix isolation approaches making the best of three worlds in the spectrometer. These aren't really pipe dreams, of course. Because, first of all, the work is well under way in the tunable diode lasers, well under way in the matrix isolation, and you are all thoroughly aware of cryogenically cooled detectors. So it is existing technology that can be applied.

Now that sounds all very rosy and I suppose we could go away rich except for the fact that we have some problems. The problems are these. First of all, that much information coming out of the tunable diode laser will be extremely confusing to the infrared spectroscopist because there are half a million known compounds that he can refer to to try to identify a molecule and he's got a whale of a lot of searching to do to identify a complete infrared spectrum. If you add more bands, his job is more difficult. If you start to reduce bands by matrix isolation effects you ease the task somewhat but he's got to be able to fit that with the spectrum or at least make a very educated guess as to what that spectrum is telling him. So these devices that are producing this kind of information, by virtue of the very output that someone has to look at, must reduce that information to some usable form. Secondly, it is not the only method that's being

applied to molecular structure determination. There are competing technologies, and the one that is most likely to grow and compete for the dollars that will be spent on this sort of thing is Raman spectroscopy, which is a scattering technique in which the sample molecules are excited with the laser. If you can put enough power into the sample without burning it up, obviously you can get far more information characteristics by increasing scatter than you can by simply reducing a known energy level. So that will be a competing technique. But on the basis of the few spectra that I've seen for the tunable diode lasers it's going to have to go some to catch up with it. The third point is, and I found this a problem myself, just last evening someone was explaining to me some functional aspects of the tunable diode lasers and in the explanation, was right with terms that sounded wonderful and these wonderful sounds were, you know, spectral resolutions and orders of magnitude. If you do this to the laser, you get 10^4 resolution, if you do this you can get 10^{12}, and you can do this with microns and you can do this with the doppler shift of the tunable diode laser. And these are all wonderful terms except that I didn't know what they meant. I'm a spectroscopist, not an optical physicist or a laser man. It was only when someone showed me a spectrum and said, "Look, this is what you can do spectrally", that I said, "Ah ha, now you're telling me something". And I think that's probably the problem that you will run into in trying to have devices like cooled infrared detectors, room temperature infrared detectors, tunable diode lasers get ultimately into the hands of the spectroscopist who must do an interpretive analysis with what he gets. If you tell him that he has all this wonderful information at his finger tips, he really will not know what you're talking about. We know this a bit by experience as a company involved in cryogenics because we started producing these lower cost and civilianized cryogenic coolers and trying to sell them as cryogenic devices in markets that were typically cryopumping markets, spectrophotometry markets, non-optical spectroscopy markets, and we fell on our face initially. We fell on our face because they could not understand the cryogenic pitch which we were giving them. It wasn't until we did application work and couched everything we did into terms of the end users application that we started to make a connection and see viable markets open for our own products. And I suspect that those problems are going to fall in these new infrared developments too.

PANEL DISCUSSION*
Prepared by A. J. LaRocca

The summary that follows depicts the discussion from the panel session as recorded on a tape recorder and transferred to these proceedings. Certain words or phrases are underlined simply to call attention to salient points or indicate change in subject matter, since there are no headings.

The first five minutes or so of discussion was lost to the tape. The recorded session picked up with Limperis discussing <u>intruder alarms</u> from the point of view of <u>low cost</u> as an attraction to the user and reliability as a requirement by the insurance company which demands this characteristic as a prerequisite to reasonable rates if not to the issuance of insurance at all. Kaplan picked up the discussion by alluding to the need for insurance on the Barnes equipment van. He stated that the insurance company did not seem to care much what type of alarm system you used, contact type or what-have-you, it was adequate to get the insurance. This, of course, may be the difference between insuring a van and a building.

Other discussion centered around this topic for a few minutes. Limperis made <u>one of the first predictions</u> of the panel session by pointing out first that a device, in order to sell, has to be inexpensive; and he was evidently considering the individual consumer in stating that the acceptable price would be under $100. This figure was derived from the assumption that the alarm manufacturer's market analysis indicated that, within the technology currently available, the number of sales would naturally warrant that figure.

Beyond this point there were a few minutes more of discussion, but most of this was peripheral to the central theme and will be ignored in this summary, even though the comments exchanged, audience included, were interesting but not necessarily pertinent. A final <u>suggestion</u> made by Kaplan, however, is included, i.e., that the large companies which do a large volume of business in intrusion alarms be approached to include IR sensors in their inventory, and list comparative advantages to offset the possible higher price. This advice was offered on the unstated assumption that there is now a device ready for the market that will work in the desired way, and which does indeed have the advantages that might offset a potentially higher price. One gets the

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*The panel consisted of the meeting speakers. Lowe was absent from the session.

impression that there has been some investigation into this area, but that the IR counterpart to existing devices either does not exist or is not competitive.

From the audience George Zissis suggested that the discussion address other subjects and asked about the possible effects of government rules and regulations, [as discussed earlier at the recent National IRIS by Eric Wormser of Barnes] regarding the sale of implements to other nations. Limperis guessed that, whereas Sensors, Inc. has not experienced an interruption of sales because of U. S. government regulation, there may be some obstacles placed in the path of selling products of the more advanced IR technology. He felt, however, that more important to him was the matter of policy regarding government patents, at which point T. Dowd, ONR, Boston, from the audience asked for clarification.

Limperis replied that a patent filed on something made under a government contract belongs to the sponsoring agency unless something is done to get exclusivity on the manufacture of the device, in which case the bureaucracy involved is enormous. On the other hand, small companies can not compete with the larger ones without exclusivity. Obtaining a license releases the device to outside agencies, but this makes it open to all companies, large and small, and the small company is put at a further disadvantage, considering that development is usually already accomplished. Furthermore, getting a device licensed for non-government use takes a number of years, according to Wormser, in most agencies not including the Defense Department. The Department of Commerce, according to Steiner, is preparing to face this problem with its Technology Incentives Program.

From the audience Ravi Sharma commented that periodically NASA goes through their patents to see which ones they will license, and the amount of time taken in this process is two or three years. Risgin said that in the past all licenses were non-exclusive, i.e., until last year when government agencies were allowed to put out exclusive licenses to the contractor who did the work, if there was a case to make that granting an exclusive license would expedite the development into the open market. The implementation of the policy is to take yet another year. In addition, the manufacturer must have contributed to the technology. Sharma said that NASA's policy allowed anyone to obtain a manufacturing license for a development not used by NASA or the developer for a period of two years. Obviously, all of these statements are unofficial and in fact subject to interpretation of the way in which they were stated at the

meeting, so anyone looking for definitive descriptions of the various policies must naturally seek the source.

Steiner read from a press release from NBS on the Experimental Technology Incentives Program to wit: "Transfer of Government-Held Technology -- Facilitated by the Government's new patent policies, we look to evaluating new arrangements under which Government patents now in force might be licensed to companies in ways which will provide adequate incentives to insure vigorous exploitation". The date of the release was not given. Steiner said the information on the Experimental Technology Incentives Program can be obtained from Dr. Harold Glaser of NBS, in charge of the program.

From the audience Tom Dowd commented that no one mentioned anything about communications, whereupon Risgin commented that the subject fell outside of the realm of IR. This brought on an exchange of comments about the use of IR in communications. Zissis felt that, in any case, we should not be restrictive in the part of the electromagnetic spectrum considered, and where the interest of this group overlapped the visible spectrum of interest we make the most of what is already covered. Limperis conjectured that, whereas one could list a variety of applications, just like communications, for in-depth study, no one has really done a thorough market analysis.

Babineaux guessed that there would be a market for FLIR's, for example, if the cost were made attractive. Limperis cited the more commonly used scanning systems on the market today and said that his discussions with Wormser led to his belief that if framing systems, such as the types used in medical applications, were reduced to $5000 the market would open up. He suggested this as a goal to be attained.

From the audience Cliff Warren stated that his experience indicated that the consumer of these types of products, at least for his Thermovision, is willing to pay the $27,000 tab to get the benefits of a more sophisticated device. That is, they would rather pay this price instead of $5000 for a product with limitations that reduce the usefulness of the instrument. Furthermore, there are other applications for which a framing system would work well, but much more primitive methods also work; not well, but they often work well enough to reduce the incentive for purchasing an expensive device, unless the old tactic proves cost-ineffective, or unless some regulation forces them to resort to the more expensive, but accurate,

method. Examples were given by Kaplan of electrically heated wind screens for helicopters and other aircraft, and inspection of insulated tank cars and trucks, in which, so far, mostly primitive methods are used, such as feeling temperature changes with the hand.

Limperis noted that in his excursions to industry, it was not always a matter of cost effectiveness that worried the manager of a plant, but often the risk that he incurs in purchasing an item which strains his budget. That is, when he is held accountable for the efficiency with which his operation is run, he usually takes the conservative approach and elects the status quo. Also the point was made that the price was often higher than that which could be approved at the user level, so that it required justification and approval at a higher level. There was a bit of discussion about whether these were always the case, but it was not resolved.

It seems that this is an area in which an independent, unbiased intermediary can perhaps establish the feasibility of a technique, procedure, or course of action. The motive of the salesman is often suspected by the buyer as not always being completely sympathetic to his (the buyer's) cause, a feeling that has been, in the light of past transactions, at least partially justified.

With the ball being passed back and forth between the panel of almost exclusively IR manufacturers, as regards the amount of expenditure which can be written off by a purchaser in the event his purchase fails justification, the chairman asked if the audience could hear from the sole IR equipment user on the panel. Lacher stated that a lot of internal politics was involved in getting the scanner that they used for what is mainly a research effort. It was tough to get and had to be justified to the top management, but once it had been approved and obtained there was not much checking by the upper management on its use, because they felt it was needed to maintain superiority over competition. In addition it could be used in other applications.

Zissis at this point wanted to know why most of the framing systems used here were of foreign origin. Supposedly through government subsidization, Sweden was able to move ahead of this country in the technology of framing systems, although this does not seem altogether obvious in light of the fact that their detectors, the heart of the system, are purchased in this country. The discussion seemed to indicate that in areas where U.S. Government restrictions are imposed, the technology of this country does not find its way into foreign markets. Much of the discussion at this point centered around the fact that the U.S. is far

ahead of other nations in the offering of point-detector systems, typified mainly by the non-contact temperature-measuring devices. Whenever the devices, on the other hand, are recognized to have military significance, the issuance of any license to sell outside of this country must have Defense Department concurrence. Similar restrictions are imposed by the Departments of State and Commerce.

[A point could easily be made here that perhaps we should put the priorities where they belong. That is, since we have not yet successfully penetrated the U.S. market with IR hardware, then the aim of IR industry should be clear. The foreign markets may be riper for picking when we find where best to apply the technology in the U.S.]

The focus of the discussion for the next several minutes was the foreign market with a few of the experiences of individual vendors. These comments did not add much more to the proceedings than had been stated heretofore. We heard from Carroll about another case that had not been discussed up to this point in the panel session. Cryogenics, it seems, suffers the same kinds of restrictions as other components and the IR systems themselves. If they fit into certain restrictive categories, and some of the liquefaction processes do, they they are prohibited for export to certain countries. Because Carroll had the floor, the discussion weaved back to spectroscopy and, in response to a question from the audience, he reiterated a statement made in one of the earlier presentations in the morning that the market for IR spectroscopy was a fairly stable one. This seems like the perfect challenge to anyone who believes otherwise.

In response to a question from Zissis who wanted to know if we could expect to find that the proliferation of small IR companies was more than the market could bear, Limperis cited his earlier predictions of market volume to emphasize that he felt that there could be more companies in the field without its being saturated. At this point the record of the discussion was interrupted as the end of the recording tape was reached.

The tape picked up the discussion on the development of the interrupted topic with a remark that showed that so-called "high-technology" companies were able to last more than five years. This gave no particular reference to IR, but the statement was made to the effect that companies tend to proliferate where the funds were made readily available, for example, supposedly as in the Boston area. Risgin asked if one reason that people already in the business are not sufficiently innovative could not be a result of a large dependence on (federal) government business, and, therefore, have not bothered to look

beyond the business they already have. No one volunteered to conjecture an answer.

Zissis identified a type of organization, an example of which is Public Technology Inc., which is much more broadly oriented in all phases of technology, and which focuses on trying to demonstrate the benefits of technology on the more-or-less local government level. [Mr. M.A. Greenbaum of Public Technology, Inc. had left earlier to catch a plane and thus was not present to make a statement.]

Kaplan described the company with the example of its method of operation. One of the items on its "technology list" is a device for fire departments which the company tries to illustrate to the heads of various fire departments, who allegedly place their confidence in the company because it "has no axe to grind", is non-profit, and works in their (the fire departments') interest. One of the purposes for existence of the company is apparently to break down the communication barrier between the user, who feels he is being fleeced, and the producer who feels that the user is not smart enough to understand anyway.

The topic was pursued for a while, with other examples, and brought about a mention of the American Society for Non-Destructive Testing which precipitated a discussion of various examples of non-destructive testing with which many people in the infrared business are aware. There were a few more comments about the society and about non-destructive testing in general. From the audience Paul Vogel, a member of the Society, lamented the fact that although there are many IR non-destructive testing applications, they are not getting sufficiently publicized. According to Vogel, in addition to the Navy's testing of rocket casings, the Army Quartermaster Corps as well as canning companies employ IR non-destructive testing. He feels that eventually it will be required that every seal in the output of the canning and packaging industry must be examined. Wormser, however, claims to have sold only one piece of equipment for that application. Vogel said that the vacuum-insulated canteens are being looked at with the non-contact thermometers, as are foamed-in-place insulated food containers, and others.

The discussion continued for a while on this subject without further specific relevance to this program, and led eventually to a resumption of the topic of education. Zissis suggested that it may be possible, with IRIA-IRIS as coordinator, to have IR people from different parts of the country available to speak to users about the basis of IR in industrial applications, or related topics. He used the travelling lecturers for the Optical Society

as an example. Kaplan felt that IRIA's existence as an impartial, government-sponsored agent might help to ease the strain between producer and user, and create a workable relationship between them. Wormser expressed hope that something could get moving also in connection with the NBS Technology Incentives Program, and subscribed to the idea of getting the information to the user possibly in the ways suggested, which included the publication of a Handbook on Application of IR Technology.

Babineaux cited an example of the need for better educational methods for the user in a recent business transaction. When Babineaux asked what they could have done to make his (the user's) decision-making task easier, he said that he would have been helped immeasurably by having had some understanding of IR ahead-of-time, but was unaware of the sources of information. He did, in fact, eventually find the "Military Handbook" (meaning the Handbook of Military IR Technology--a formidable book indeed, even for the experienced) and was then able to ask intelligent questions. Babineaux asked Zissis about his intention to update the Handbook, to which Zissis responded that he had intended, perhaps, to publish monographs of current interest, and application notes. This brought a plea from Wormser to omit the term "Military" which seems in the past to have implied an exclusivity which, in fact, did not really exist, in the Handbook.

With the end of the session (and the day) rapidly approaching, a final question was raised to the effect that although a lot had been accomplished at this meeting, what happens after this? At Wormer's suggestion of the formation of a committee, a short discussion got started which led to the agreement among panelists and audience alike that this should be only the first in a series of meetings and other activities to keep the ball rolling. Wormser wanted to see a broader-based meeting which would include non-military users. Several suggestions were made regarding thetype of people who should be invited; and generous offers were made by people attending, to do whatever they could to help. The chairman verbally accepted each and every offer.

No one objected to the plea from Zissis to maintain the focus of interest limited to the topic of the meeting, and not be tempted to stray very far afield on the pretext that IR interfaces a lot of disciplines, while keeping our devotion confined. After a few more minutes of discussion on this subject, with a request for feedback from the audience, the meeting was adjourned.

APPENDIX A

EXPANSION OF INFRARED TECHNOLOGY INTO THE CIVILIAN MARKET

ATTENDANCE LIST

20 September 1972

BABINEAUX, T. L.	Optical Coating Laboratory, Inc./Santa Rosa, CA
BIRKO, Arnold	Ford Motor Co./Dearborn, MI
CARROLL, John E.	Cryogenic Technology Inc./Waltham, MA
CAVALIER, James J.	Orchard Lake, MI
CUSSEN, Arthur J.	Electro Optical Industries Inc./Santa Barbara, CA
DENECKE, Mildred F.	Environmental Research Institute of Michigan/ Ann Arbor, MI
DOWD, T. B.	Office of Naval Research/Boston, MA
GREENBAUM, Miles A.	Public Technology, Inc./Washington, DC
INTRIERI, A.	Dynarad/Norwood, MA
JAMRON, Richard	Environmental Research Institute of Michigan/ Ann Arbor, MI
KAPLAN, Herb	Barnes Engineering Co./Stamford, CT
LACHER, M. B.	Owens-Corning Fiberglas/Granville, OH
LA ROCCA, Anthony J.	Environmental Research Institute of Michigan/ Ann Arbor, MI
LARSEN, Leo M.	Environmental Research Institute of Michigan/ Ann Arbor, MI
LIMPERIS, Thomas	Sensors, Inc./Ann Arbor, MI
LIVISAY, J. P.	Environmental Research Institute of Michigan/ Ann Arbor, MI
LLOYD, Don B.	Honeywell/Lexington, MA
LOWE, Donald S.	Bendix Corp./Ann Arbor, MI
LUNDQUIST, S. G.	Hughes Aircraft Co./Oceanside, CA
MC ARDLE, John	E G & G/Bedford, MA
OGAWA, Herbert F.	PIRE Inc./Princeton, NJ
QUIST, Theodore M.	MIT/Lincoln Laboratory/Lexington, MA
RISGIN, Ojars	Sensors, Inc./Ann Arbor, MI
SCOTT, Ronald S.	Princeton Infrared Equipment Inc./Princeton, NJ

SHARMA, Ravi*	Willow Run Laboratories, The University of Michigan/Ann Arbor, MI
STANFILL, Daniel F.	Arthur D. Little Inc./Cambridge, MA
STEINER, Bruce	National Bureau of Standards/Washington, DC
STOLP, W. J.	Eastman Kodak Co./Rochester, NY
VOGEL, Paul E. J.	U.S. Army M & MRC/Watertown, MA
WARREN, Cliff	AGA Corp./St. Charles, MO
WILCOX, Howard C.	Santa Barbara Research Center/Goleta, CA
WORMSER, Eric M.	Barnes Engineering Co./Stamford, CT
WRIGHT, Ford L.	Daedalus Enterprises/Ann Arbor, MI
YOSHIMOTO, Henry	Hughes Aircraft Co./Culver City, CA
ZISSIS, George J.	Environmental Research Institute of Michigan/ Ann Arbor, MI
ZMARZLY, Fred	Optical Coating Lab., Inc./Santa Rosa, CA

*Visiting Scientist from: Dept. of Space Headquarters
Government of India
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APPENDIX B

The following letters were received after the seminar from two of the participants and are included because they add to the general discussion and are indicative of the enthusiasm evidenced at the Conference.

sensors, inc.

October 2, 1972

George Zissis
and
A. J. LaRocca
Building 2041
Willow Run Laboratory
Ann Arbor, Michigan 48107

Dear George & Tony:

Thank you for the opportunity to participate in an interesting symposium. Everything went reasonably well up to the point of discussing the action items at the end of the meeting. If you remember the question was asked about NDT and then the conversation suddenly was concentrated totally on the question of how to educate the ASNT people and the ASQC people. I feel that this emphasis was not warranted at all. The non-destructive testing equipment market is small compared to others that are possible. I cautiously named a few (insect pest controls, security alarm, and fire suppression) and I am quite sure there are many more.

If the basic objective of the meeting was to consider expanding infrared technology into non-government markets, then the conversation dealing with action items should have been concentrated on how to educate the infrared technologist. How do you get him to think about our country's major problems creatively? Usually money will do it. Provide the dough and most of them will create every time. Some approaches to this might be:

1. Put together a panel of creative infrareders that can look at a list of the world's problems and then think of solutions using infrared.

2. Give the Environmental Research Institute of Michigan a contract to do this. If they do a good job and publish the results, industry will take it from there.

3. Have someone tour around the various infrared companies and institutions and accumulate a list of possible infrared applications.

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After the new infrared products are listed then their economic benefits should be analyzed to see how the costs compare with the benefits.

The question of the government's patent requirements was considered only briefly resulting in no action items at all. I don't believe the people understood the problem. Is there something we can do about this with the help of Tom Dowd, IRIS, or others?

Now let's get back to the NDT thing. Lectures on infrared at ASNT and ASQC meetings have been presented in the past and will, I'm sure, be presented in the future regardless of what IRIS does. Limperis, Kapam, Vanzetti, Grant, Ginsberg, Earing, Risgin, and others have done it in the past and will continue to do it in the future - adding more lectures won't appreciably expand infrared into the NDT field. The major "user" of NDT equipment is the manufacturing engineer and he usually doesn't show up at the ASNT and ASQC meetings. The research people do. "Let me make this (point) perfectly clear." There are two groups concerned with testing in most large industrial firms:

- The research groups that are supposed to invent and/ or test new NDT and DT devices and methods,

- The production group that is concerned only with the number and quality of widgets produced each day. The latter group is the potential large volume buyer of infrared NDT equipment. The image of infrared in his eyes has been tarnished badly by a large number of errors perpetrated by infrareders because of <u>their</u> ignorance. Listed below are a few examples for your information:

1.0 In the auto industry hand held radiometers have been purchased to measure the average temperatures of objects under test. The ambient temperature in these rooms is 105°F according to government specifications. Those radiometers that use PbS detectors become inoperative because PbS won't hold up at 105°F. I have personally seen many of these devices setting on a shelf gathering dust. It's then hard to go to these people and ask them to buy a novel infrared what-cha-may-call-it to solve another problem. He feels that the sophisticated infrared technology can't be used for his problems

2.0 Metal and plastic processing industries using infrared radiometers have encountered serious drift problems in their sensors that are not mentioned in the specifications listed in the sales literature. Perhaps we should standardize infrared equipment specs and maybe have an independent NDT test lab to certify the equipment.

3.0 Most infrared equipment sold for NDT applications is too fragile. One major tire company bought an infrared system to look at tires under test. The tire exploded during one of the tests and the system was damaged at a considerable cost. The NDT engineer that bought that equipment believes that all infrared equipment is too fragile and too costly for use <u>anywhere</u> in the tire industry.

The best thing we can do for the NDT guy is to give him a catalog of the various uses of infrared for NDT along with appropriate formulas to do specific analysis. Also, get this type of information published in the "Non-destruction Testing Handbook." The editor is McMasters from Ohio State University. As I mentioned in my paper the manufacturing engineers and Quality Control engineers have volumes of handbooks describing x-ray methods and equipment, magniflux, optical comparators, etc., but they have <u>nothing</u> on infrared.

Perhaps a new trade association should be established for commerical infrared. IRIS is probably too closely tied to the military to be converted over to the commercial end; besides, companies like IRCON who do no military work to speak of don't communicate with IRIS. Perhaps the trade association would do the following:

1. Sponsor points 1, 2, and 3 on page 1.

2. Work with IRIS, IRIA, and DOD on declsssifying and publishing the material in their files.

3. Sponsor advertising on a small scale on what infrared can do for NDT, process control, etc.

4. Work on standardizing detectors, filters and other components; work out a standard format for specs.

5. Publish (with NBS, DOD agencies like Newark & Huntsville, etc.) standard calibration procedures for radiometers, scanners, etc. to permit users to recalibrate and check their equipment with confidence.

6. Do general marketing, like with the Public Technology outfit mentioned in the discussion, and keep statistics.

7. Lobby on patent policy, export restrictions and other government areas.

It's also worth while pushing infrared in the Instrument Society of America (ISA) which somebody mentioned at the meeting. This outfit covers the whole spectrum of instrument uses.

Sincerely,

Thomas Limperis
President

Ojars Risgin
Vice President

TL/OR:cvn

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October 2, 1972

Mr. A. LaRocca
Institute of Science and Technology
University of Michigan
P.O. Box 618
Ann Arbor, Michigan 48107

Dear Mr. LaRocca:

First, I would like to thank you for providing me with a copy of the notes on the Fundamentals of Infrared Technology.

Secondly, I would like to thank you again for your response to my request for information concerning the Infrared Civilian Market meeting, as it helped me decide to attend.

Lastly, I would also like to take the opportunity to tell you that I thought you did an outstanding job in organizing and conducting that meeting. I thought it was very good and although the attendance was not what I know you expected, I think its size enabled a more meaningful dialogue between equipment manufacturers than normally would have occured.

I, like yourself, and I'm sure so many others know that there is a very real viable need for infrared equipment in the civilian/industrial market. I believe the realization of the full potential of this market can only come about through the proper promotion and education of the potential end-users on the capabilities of infrared technology - and more importantly - the benefits it will provide in terms that businessmen can readily understand (i.e. increased cost savings, improved quality, etc.). I

believe IRIA and similar-type organizations (e.g. ASNT & IEEE infrared committees), properly supported - especially by infrared equipment and component manufacturers - can do an excellent job in this area.

It will also require progressive thinking and action by the IR equipment manufacturers to provide hardware that satisfies the needs of the customer. I know this sounds trite, but to date, most IR equipment manufacturers have tried to take equipment produced to satisfy military-type operations and "push" it in the civilian/industrial market. The general poor sales record in this market area, I believe, should attest to the futility of this type-approach. High cost, high performance, complicated or sophisticated systems that can do many wonderful things, except the job the customer had in mind - simply and in a cost effective way - just will not generate large volume sales or good applications to the extent that we would like.

So much for the problems of the past or as some management people like to say "excuses" for poor sales. What can we do now is the main point. I believe the meeting you just conducted was a big help. It enabled the management people who are producing and selling IR equipment to understand that their problems are not unique and that they are not alone. I know it was educating for me to know that other manufacturers were experiencing similar-type problems and also that there are capable, dedicated people like yourself and Mr. Zissis willing to help. I believe similar-type meetings or situations where concerned parties with common-type problems can openly discuss what they've done and are doing to open up the civilian infrared market can be very helpful. I feel if we all think in terms of the big picture - educating people on the capabilities and benefits of infrared technology without trying to openly sell them a particular product - it is also important. When I worked at the Boeing Company, I often attended a siminar or meeting whose intention was to be educational, but which unfortunately, turned out to be a sales presentation of that manufacturer's equipment. It just left a bad impression with the majority of the people who attended. Therefore, I think equipment manufacturers should educate more on the why's and wherefore's of infrared and less on why their equipment is the only kind available to do the job.

I think, as you pointed out, the first thing we should do in this area is prepare an infrared handbook without any military association. As part of my duties as chairman of the Infrared Educational Subcommittee of the American Society of Nondestructive Testing (ASNT), I have been trying to do just this. However, business priorities and lack of support from other people have slowed the effort down. Since you indicated that you were going to prepare an infrared handbook, I thought I would enclose, for whatever help it can provide, an outline on what I was planning to do. I also will be happy to help you in any way you think I can. So please feel free to call me anytime.

I have also enclosed a Bibiliography of Infrared and Thermal Techniques for nondestructive testing that I prepared in 1970. I am in the process of updating this and would appreciate any inputs and comments you or your colleagues may have. I feel if we can publicize the successful applications of infrared technology, then we stand a better chance of convincing people and potential end-users of its enormous capabilities.

Very truly yours,

A.J. Intrieri

A.J. Intrieri
Vice President

AJI:jw
Enclosures